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DRUM HANDLING PRACTICES AT HAZARDOUS WASTE SITES

by

K. Wagner, R. Wetzel
H. Bryson, C. Furman
A. Wickline, and V. Hodge
JRB Associates
McLean, Virginia 22102

Contract No. 68-03-3113

Project Officer

Anthony N. Tafuri
Hazardous Waste Engineering Research Laboratory
Releases Control Branch
Edison, New Jersey 08837

HAZARDOUS WASTE ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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The purpose of this research effort was to provide technical guidance on planning and implementing safe and cost-effective response actions applicable to hazardous waste sites containing drums.

The manual provides detailed technical guidance on methods, procedures, and equipment suitable for removing drummed wastes. Information is included on locating buried drums; excavation and onsite transfer; drum staging, opening, and sampling; waste consolidation; and temporary storage and shipping.

Each of these operations is discussed in terms of the equipment and procedures used in carrying out specific activities; health and safety procedures; measures for protecting the environment and public welfare; and factors affecting costs. Information is also included on the applications and limitations of the following remedial measures for controlling or containing migration of wastes: surface capping, surface water controls, groundwater pumping, subsurface drains, slurry walls, and in-situ treatment techniques.

This manual will be useful to On-Scene Coordinators, Federal, state, and local officials, and private firms that plan and implement response actions at sites containing drums.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of state and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This manual was conceived and developed to provide guidance in the planning, selection, and implementation of safe and effective remedial methods applicable to hazardous waste sites containing drums. In tandem with the National Contingency Plan, this manual will provide guidance to Federal and state personnel and private firms in developing technically sound, safe, and cost-effective remedies for sites containing buried drums or drums stored aboveground. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

David G. Stephan
Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

The purpose of this research effort was to provide technical guidance on planning and implementing safe and cost-effective response actions applicable to hazardous waste sites containing drums.

The manual provides detailed technical guidance on methods, procedures, and equipment suitable for removing drummed wastes. Information is included on locating buried drums; excavation and onsite transfer; drum staging, opening, and sampling; waste consolidation; and temporary storage and shipping.

Each of these operations is discussed in terms of the equipment and procedures used in carrying out specific activities; health and safety procedures; measures for protecting the environment and public welfare; and factors affecting costs. Information is also included on the applications and limitations of the following remedial measures for controlling or containing migration of wastes: surface capping, surface water controls, groundwater pumping, subsurface drains, slurry walls, and in-situ treatment techniques.

This manual will be useful to on-scene coordinators, Federal, state, and local officials, and private firms that plan and implement response actions at sites containing drums.

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SECTION 1

INTRODUCTION

The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) establishes a nationwide program for the cleanup of uncontrolled hazardous waste sites. This program is implemented through provisions of the National Contingency Plan (NCP), 40 CFR Part 300, which sets forth the process by which response actions will be selected and evaluated. Such response actions must meet the need for protection of public health, welfare, and the environment in the most cost-effective manner. Therefore, three broad criteria have been established for selecting and evaluating response actions: engineering feasibility; costs; and public health, environmental, and institutional impacts. The objective of this manual is to provide technical guidance relative to these criteria on the selection and implementation of response actions at uncontrolled hazardous waste sites with drums.

The need for technical guidance in the area of response actions at hazardous waste sites with drums has become evident since the establishment of CERCLA. The results of a 1982 survey of disposal practices at uncontrolled waste sites indicated that over 20 percent of the sites have major drum-related problems (U.S. EPA, 1984a). Experience has shown that there are a number of health, safety, and environmental hazards unique to drum handling operations. In addition, since the implementation of CERCLA, a number of removal and remedial actions have been implemented at hazardous waste sites with drums. The experience gained from these activities and presented in this manual will be invaluable for future response actions at similar sites.

This manual has been prepared to provide technical guidance to on-scene coordinators (OSC), Federal, state, and local officials, private firms, and U.S. Environmental Protection Agency (EPA) field personnel. It presents procedures and methods for planning and implementing cost-effective response actions applicable to drum problems requiring one or more of the three response categories outlined in the NCP: removal, surface cleanup, and subsurface remedial action. The major focus of the document is to provide guidance specific to the removal of drummed wastes including such activities as locating, excavating, staging, opening, and transporting drums, and consolidating wastes from drums. Information is also presented on the use of source control measures (e.g., pumping, slurry walls, drains) to contain or control the migration of wastes from drums. The information on source control measures is presented in the form of summary tables with references because considerable guidance is available on the design and implementaiton of these technologies.

Recognizing that every site is unique in its drum-related problems, the U.S. EPA and the contractors involved in preparing this manual have generally taken the approach of outlining the planning process and presenting various options for handling drums, rather than recommending one specific method that should be steadfastly followed. The exception to this is when the appropriate regulations [e.g., CERCLA, Resource Conservation Recovery Act (RCRA), Department of Transportation (DOT)] require a certain method or procedure or when worker safety, public health, or the environment can only be adequately protected by one specific method or procedure.

Section 3 of the manual draws on more detailed information that is presented throughout Sections 4 through 11 to provide summary guidance for selecting and implementing drum handling methods based on the following criteria:

- Technical feasibility
- Protection of worker health and safety
- Protection of the environment and public health
- Costs.

Section 4 discusses procedures for detecting, locating, and inventorying drums--activities that typically are undertaken as part of the preliminary assessment or remedial investigation. Section 5 discusses site preparation activities including measures for improving site access, design and setup of the various operating areas and support facilities needed for the response actions, and measures for improving site drainage. Procedures for determining drum integrity and unsafe contaminant levels in and around drum handling activities are considered in Section 6. Section 7 addresses equipment and procedures for excavating buried drums and maneuvering drums onsite. Equipment and procedures for staging and opening drums are covered in Section 8, and Section 9 discusses procedures for consolidating or repackaging drum contents. Guidance on interim storage and transportation is presented in Section 10. Section 11 employs a series of tables to summarize the applicability and limitations of various remedial techniques for controlling or containing the migration of wastes from drums. The following remedial actions are discussed: surface capping; surface water controls; groundwater pumping; subsurface drains; and in-situ treatment methods.

SECTION 2

CONCLUSIONS

Response actions involving the offsite removal of drummed wastes are unique in many respects from response actions taken at other sites. As a result of associated safety and environmental hazards, a number of specialized equipment types have been developed for handling drums, and a number of good operating procedures have evolved.

Much of the equipment used for drum handling has been specially adapted for the safe handling of hazardous wastes. Where conventional construction equipment such as backhoes or front-end loaders are used, they can be equipped with plexiglas safety shields or other modifications to reduce potential safety hazards. For example, nonsparking bucket teeth can be used to prevent explosions and a "morman bar" can be used to cover bucket teeth to prevent drum rupture. One of the most significant equipment modifications is the flexible barrel grappler, which consists of a grapple attachment suitable for mounting on a hydraulic backhoe. The grapplier can grab and lift various sizes of drums from any angle and relocate them without manual assistance. Remotely operated drum plungers and debungers used for drum opening are other important developments. Another equipment type for handling hazardous materials is the industrial vacuum (i.e., the Vactor or Supersucker) which can convert from liquids to solids handling and can convey materials over substantial distances.

Procedures and protocols have been developed for the safe and efficient handling of drums. These methods provide reasonable precautions to prevent drum ruptures, explosions, fires, toxic releases, and contamination of groundwater and surface waters. Some of the more important procedures and protocols that have evolved include the following:

- The site operating areas should be designed to promote the most efficient and safest operation possible. The layout ideally includes one or more areas for staging the drums and separate areas for opening drums, consolidating their contents, equipment decontamination, and temporary storage of contaminated soils and drums. Within each area, measures should be taken to provide secondary containment. Such measures should be consistent with the types of hazards posed by accidental releases. Highly hazardous materials (e.g., radioactive materials, explosives, and gas cylinders) should be isolated to the extent possible and placed in separate, remote staging or storage areas.

- Air monitoring equipment should be used extensively during such operations as drum excavation, opening, consolidation, and storage to provide an indication of unsafe levels of toxics, explosives, or radioactive materials.

- Drums with poor integrity should be overpacked or their contents transferred as soon as they are identified.

- Compatibility testing should be conducted on all drums to determine which wastes can be successfully consolidated. Efforts should be made to maximize the consolidation of compatible wastes since this provides for the most cost-effective means of transport and disposal. Once incompatible waste types have been identified, they should be segregated for all subsequent activities (generally consolidation, temporary storage, and transportation).

- Direct handling of drums should be minimized to the extent practical by use of such equipment types as the grappler, remote drum opening equipment, and industrial vacuum trucks.

Drum handling operations can be conducted safely and cost-effectively by a careful planning process that considers these procedures and others for protection of health and safety, protection of the environment, and technical limitations and applications of various equipment types.

In addition to methods for removing drummed wastes, there are also a number of source control measures, such as capping, surface water controls, slurry walls, and groundwater pumping, which are suitable for containing or controlling migration of wastes from drums. These measures are not unique to drum handling but have a much broader applicability for controlling bulk hazardous waste migrations from landfills, impoundments, etc. Although they are summarized in this manual, the U.S. EPA has funded separate studies to determine the f[illegible]bility, design, and construction of these remedial action techniques.

SECTION 3

SELECTION OF DRUM HANDLING METHODS

Selection and detailed design of response actions involving removal of wastes contained in drums is based on four broad technical criteria consistent with the requirements of the NCP. These are:

- Engineering feasibility of various equipment types including waste and site-specific factors which affect equipment performance and any inherent limitations of the equipment
- Protection of health and safety of field personnel
- Protection of the environment and public welfare
- Costs.

Each of these criteria are dealt with in considerable detail in Sections 4 through 10 of this report in relation to specific drum handling activities (e.g., excavation, opening, consolidation, etc.). This section draws on the detailed information presented throughout these sections and summarizes the data by classifying them under the four broad criteria listed above.

ENGINEERING FEASIBILITY

A variety of procedures, equipment types, and equipment modifications have been used to respond to various conditions found at uncontrolled waste sites. A number of factors go into the selection of equipment for a particular response action. The selection process considers site and waste characteristics that limit the feasibility and effectiveness of various equipment types and drum handling methods as well as the performance record and the inherent operation and maintenance problem of the equipment. The engineering feasibility of various equipment and procedures can best be judged in terms of the following factors:

- Number of drums (Table 1A)
- Site accessibility/location (Table 1B)
- Depth of burial/surface disposal (Table 1C)

- Hydrogeologic conditions (Table 1D)
- Drum integrity (Table 1E)
- Hazard/toxicity of the drum's contents (Table 1F).

Tables 1A through 1F, at the end of this section, summarize the use of various equipment and methods for handling drums under these various conditions.

HEALTH AND SAFETY OF FIELD PERSONNEL

The U.S. EPA and the Occupational Safety and Health Administration (OSHA) have published extensive guidelines on health and safety procedures applicable to the cleanup of uncontrolled hazardous waste sites. Since this guidance is already available, it will not be covered in this report. Procedures for field health and safety should be consistent with the following guidance:

- Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Section 111(c)(6)
- EPA Order 1440.2 - Health and Safety Requirements for Employees Engaged in Field Activities
- EPA Order 1440.13 - Respiratory Protection
- EPA Occupational Health and Safety Manual (U.S. EPA, 1980)
- EPA Interim Standard Operating Safety Guide (U.S. EPA, September 1982)
- Applicable OSHA Standards.

The field health and safety procedures should be detailed in a site-specific plan that addresses the elements shown in Table 2, at the end of this section, (based on Buecker and Bradford, 1982). In addition, the plan should address health and safety procedures and protocols that are unique to drum handling operations. These measures, summarized in Table 3, include the use of specialized equipment adapted for the safe handling of drums, such as remotely operated drum-opening equipment, as well as good safety practices, such as the prompt isolation of potentially explosive or radioactive wastes.

In addition to health and safety procedures, a site-specific spill contingency plan should also be developed. The plan should outline procedures/actions to be followed in the event of an emergency condition, starting with the occurrence of a spill, and defining real-time responsibilities and procedures for the following types of emergencies:

- Fires and explosions
- Major spills
- Medical emergencies
- Weather extremes
- Civil disobedience/unauthorized site entry.

The contingency plan should accomplish the following objectives:

- Identify scenarios that could lead to an emergency (e.g., explosion of containers of shock-, pressure-, or heat-sensitive materials; equipment rollover or cave-ins; chain reactions resulting in an explosion or fire; etc.)
- Outline procedures for various types of emergencies
- List the response team organization and responsibilities including cleanup contractors, local authorities, and services (e.g., fire, police, health services), OSC, and State or EPA officials.

PROTECTION OF THE ENVIRONMENT AND PUBLIC WELFARE

There are numerous tools or measures available for minimizing environmental releases during drum handling. These tools or measures can be divided into two broad categories:

1. Measures that prevent environmental releases, such as overpacking or pumping the contents of leaking drums
2. Tools that mitigate or contain spills once they have occurred, such as perimeter dikes.

Mitigative or containment measures generally include low-cost, easy-to-implement techniques such as the use of dikes and plastic liners to contain spills in work areas. A Spills Control and Contingency Plan, prepared as part of the Remedial Design, should outline specific measures for mitigating and containing spills.

The selection of tools or measures to minimize environmental releases depends upon the extent to which the site has already been degraded, the proximity of surrounding populations, the potential for contamination of groundwater and surface water, and cost impacts.

Table 4 summarizes preventive and mitigative measures for controlling environmental releases during drum handling.

COSTS

Costs consist of all financial (cash) outlays required to implement a response action, including: engineering, design, installation, and capital outlays; and other costs, as appropriate. Remedial action costs can range from as low as $60/drum to as much as $1500/drum or more (U.S. EPA, 1984a). This wide range is the result of site-specific requirements, waste types, number of drums, drum condition, and transportation and disposal costs.

Costs associated with remedial actions involving drum handling can be grouped into four categories based on the activities conducted.

- Worker health and safety
- Excavation
- Containerization (overpacking)
- Removal/transport.

Because of the variability between sites, it is difficult to assign a specific cost or range of costs to these activities. The interrelationship of these activities in all phases of cleanup operations preclude isolation of the cost impact of each element. However, general guidelines can be provided for each category as to its impact on the total cost of cleanup.

To ensure adequate worker protection it is necessary to test and assess the potential hazards at the site and establish the appropriate protection levels. The safety equipment required for a particular level of protection (e.g., level A, B, C, etc.) will have an impact on the project cost. However, the cost of protective equipment is secondary to the cost associated with the increase in time required for workers to complete activities using protection levels A or B. Under these conditions, worker mobility is drastically reduced, requiring additional time to accomplish even simple tasks.

Excavation costs include equipment rental/lease and mobilization, and operator time. Costs can be minimized by selecting the appropriate equipment for the job based on site-specific conditions. When specialized equipment is necessary to handle unusual problems, costs will increase; standard types of equipment (e.g., backhoe, forklift, etc.) generally incur lower costs. Mobilization of excavation equipment will also add to the remedial action cost. However, job size does not significantly affect this cost. Some studies of remedial actions (U.S. EPA, 1984a) indicate that the excavation of drums does not add significantly to the cost of a remedial action. This suggests that the added cost of excavation equipment is less significant than other cost items such as treatment or protective equipment necessary for high risk sites.

At sites requiring overpacking or recontainerization of wastes, many specialized service costs may be incurred in addition to the purchase of containers for overpacking. Where drums are extensively damaged or wastes are leaking onto the surface, vacuum systems may be necessary to collect and contain the waste. This type of response action usually results in additional costs for crushing and emptying the original drums after their contents have been removed. The drum size required for overpacking will also affect the cost. For example, overpacking 30-gallon drums requires a 55-gallon overpack, while overpacking 55-gallon drums requires an 80-gallon overpack. The impact of overpacking costs on overall response costs may be highly variable.

Costs for removal and transport usually have a significant impact on total remedial action costs. These costs are extremely variable depending on the waste type, distance to an acceptable disposal site, drum size and condition , drum location, and personnel protective equipment required for safe handling. In addition, careful management of the more hazardous waste types increases the time necessary for the various elements of the operation (e.g., labor and equipment). It should be determined on a site-specific basis whether bulking is feasible. This procedure can significantly reduce removal and transportation costs compared to costs associated with handling individual drums. Elements of the transport and removal cost are also reflected in the previous discussion of site cost activities (i.e., worker safety, excavation, containerization).

Throughout the four activities, economies of scale will affect the total cost per drum. There is generally a direct relationship between the total site costs and the number of drums involved and an inverse relationship between the total site costs and the unit cost per drum. Certain minimum costs, however, are also generally charged for component tasks independent of the size of the effort such as mobilization of technicians and equipment or transportation. Associated costs can be minimized by the selection of the most cost-effective contractor and equipment types and by effective management of the cleanup operation.

The following list presents several monetary costs that should be considered and quantified, when possible, during a cost-effective analysis:

- Potential outlays including related administrative costs to obtain necessary permits, licenses, etc.
- Engineering expenses, such as technical services related to sampling, testing, designing, managing, and reviewing the remedial measure
- Land-related expenses for the rental or purchase of rights-of-way and easements, as well as expenditures for land/site preparation
- Construction costs including direct outlays for equipment, hardware, and materials
- Costs for disposing of wastes at an approved off-site facility

- Startup costs comprising operator training, temporary professional services, additional testing, monitoring, process controls, and equipment or materials transport costs
- Labor costs including all payments for wages, salaries, training, overhead, and fringe benefits to workers employed at the site.

In selecting the appropriate contractor or equipment, the following points should be considered:

- Length of contractor's work day--by specifying that equipment operate for 12 hours rather than 8 hours, the cost of equipment downtime can be minimized
- Contractor's performance record with proposed equipment/methods
- Equipment efficiency under specific site conditions
- Equipment dispatching time (transport and setup)
- The extent to which a piece of equipment can perform several functions thereby minimizing idle time and costs for equipment mobilization
- The ability of one contractor to handle the entire cleanup operation
- The location of potential treatment and disposal facilities and their cost per volume of waste.

Once the contractor is selected, additional cost savings can be made by close management of the cleanup operation.

A project schedule and cost estimate for each cleanup activity should be outlined in the Remedial Design. These guidelines provide reasonable assurance of completing the cleanup within the specified time and budget. However, they are subject to change as cleanup reveals additional information about the number of drums, their contents, and their integrity. A schedule of project milestones provides some guidance for scheduling certain pieces of equipment or certain contractors at the site, thereby minimizing the amount of idle time for equipment and field personnel.

In addition, when the time and costs for a particular activity exceed that which was planned, it may be possible to modify the approach for subsequent activities to maintain costs without sacrificing worker safety or protection of sensitive environmental areas.

TABLE 1A. ENGINEERING FEASIBILITY AND EFFECTIVENESS OF VARIOUS DRUM HANDLING METHODS

NUMBER OF DRUMS		
LOCATION AND INVENTORY	**EXCAVATION**	**DRUM STAGING**
• Expenditures for remote sensing must be kept in perspective; if the number of buried drums is small, use a simple remote sensing tool (i.e., metal detector) to locate drums; may not be worth the expense to quantify; hand-held tools are suitable for small sites, whereas vehicle-towed equipment is sometimes needed at large sites	• For large numbers of drums use highly mobile, high-production equipment (i.e., backhoes, grapplers, rubber tired loaders, industrial vacuums); several equipment types can be employed economically at sites with over 1000 drums	• High-production equipment (grappler, front-end loader) should be used for staging and transferring large numbers of drums
• A random sampling of drums aboveground may involve 5 to 25 percent of the drums depending upon the total number of drums as well as their hazard and accessibility	• For small sites (<500 drums) use versatile equipment such as combined backhoe-front-end loader and limit number of vehicles onsite	• Where there are a large number of drums, staging and opening the drums in shifts should be considered if spacing is inadequate
		• If the number of drums is very large, it may be necessary to stage and open the drums in the same area; when this is the case, drums should be staged with adequate space between aisles to allow access of remote opening equipment and adequate space between drums to prevent chain reactions in the event of fire or explosion

(continued)

TABLE 1A. (continued)

NUMBER OF DRUMS		
DRUM OPENING	CONSOLIDATION/RECONTAINERIZATION	INTERIM STORAGE AND TRANSPORTATION
• For large numbers (>500) of drums, a backhoe plunger or a remote conveyor should be considered for drum opening	• Where large numbers of compatible liquid wastes are present, their contents can usually be bulked rather than shipping the drums individually. Large capacity vacuum equipment is generally preferred over skid-mounted units providing these vehicles have access to the site	• State transportation requirements must be consulted to determine the number of drums and volume of liquid that can be transported in a load
• For small numbers of drums, hand tools can be considered depending on conditions of drums and drum contents	• Onsite treatment options should be considered for a large number of drums	
	• Drum crushers or shredders are generally used when large numbers of empty drums are present. If the number of empty drums is few, backhoes and loaders can be used for crushing	
	• Solids are generally shipped in DOT approved drums although they can be shipped in bulk along with heavily contaminated soils, depending upon the requirements of the disposal facility	

TABLE 1B. ENGINEERING FEASIBILITY AND EFFECTIVENESS OF VARIOUS DRUM HANDLING METHODS

SITE ACCESSIBILITY/LOCATION

LOCATION AND INVENTORY	EXCAVATION	DRUM STAGING
• Remote wooded site may require that geophysical surveying be done manually rather than by vehicle; clearing and grubbing may be needed to conduct continuous surveys • Certain cultural features commonly present in congested or populated areas can interfere with geophysical surveying (i.e., fencing, buried utilities, passing cars); the fluxgate gradiometer is least sensitive to such interferences • Preparing an inventory of drums aboveground can be hazardous if the site is congested. Minimize hazards by (1) staging drums for opening, (2) using remote opening equipment, and (3) keeping random sampling to a minimum	• Remote sites may require special site preparation, such as clearing and grubbing for easier access, and may dictate use of fewer, larger equipment types (backhoes, grapplers, crawlers, tractors, cranes) • For readily accessible sites, equipment size and number are not limited; favors mobile rubber-tired vehicles (bobcats and backhoes) • For congested, urban sites, may need smaller machinery (forklifts and loaders) for lifting and transfer; may also use hoists or slings to lift drums from congested areas • Cranes and draglines may be used if a particularly long reach is required to lift drums in a congested area	• Where adequate space is available, drum staging should be segregated from drum opening • If site is congested, drums may be staged, opened, and sampled in shifts to provide adequate work space; alternatively, drums may be staged and opened in the same work area; in a combined staging and opening area, drums should be staged so there is adequate space between drums to minimize a chain reaction in the event of a fire or explosion and adequate space between rows to allow access to drums by remote opening equipment

(continued)

TABLE 1B. (Continued)

SITE ACCESSIBILITY/LOCATION		
DRUM OPENING	CONSOLIDATION/RECONTAINERIZATION	INTERIM STORAGE AND TRANSPORTATION
• See preceding discussion on staging	• Skid-mounted vacuum units may be needed for waste consolidation in inaccessible areas • Location of the site with respect to treatment/disposal facilities should be considered prior to consolidation/recontainerization • Onsite treatment of wastes and soils can be a viable option, particularly if the site is not in a populated area; detonation of lab packs onsite should only be considered if the site is remote	• Storage area should be as distant as possible from populated areas; reactives and explosives should be stored away from buildings

TABLE 1C. ENGINEERING FEASIBILITY AND EFFECTIVENESS OF VARIOUS DRUM HANDLING METHODS

DEPTH OF BURIAL/SURFACE DISPOSAL		
LOCATION AND INVENTORY	**EXCAVATION**	**DRUM STAGING**
• Geophysical surveying is used to determine depth of burial; metal detectors are suitable for locating shallow drums; magnetometry, electrical conductivity, and resistivity can detect drums to considerable depths • Preparation of a drum inventory may be limited to drums aboveground; however, geophysical surveying can be used to obtain a rough approximation of the number of drums	• Excavation of buried drums requires use of backhoe, grappler, etc.; drums buried deeper than about 10 meters (30 feet) may require use of a crane or dragline or the excavation of a "working platform" parallel to the trench or pit; backhoe or front-end loaders can be used for excavation of very shallow drums	• Not applicable
DRUM OPENING	**CONSOLIDATION/RECONTAINERIZATION**	**INTERIM STORAGE AND TRANSPORTATION**
• Not Applicable	• Not Applicable	• Not Applicable

TABLE 1D. ENGINEERING FEASIBILITY AND EFFECTIVENESS OF VARIOUS DRUM HANDLING METHODS

HYDROGEOLOGIC CONDITIONS		
LOCATION AND INVENTORY	**EXCAVATION**	**DRUM STAGING**
• Presence of a high water table may prevent use of a vehicle to tow remote sensing equipment • Where groundwater is saline, ground-penetrating radar, electromagnetics, and electrical resistivity may be ineffective • Complex stratigraphy can make interpretation of resistivity and seismic refraction data very complex • Ground-penetrating radar may be ineffective in clay soils	• Water-logged sites may require surface runoff diversion with trenches and berms to improve drainage; wet, muddy sites favor equipment mounted with good flotation tires or crawler-mounted vehicles; swamp pads (extra-wide crawler tracks); and timber mats may also be useful • For dry sites, less site preparation is needed and mobile, rubber-tired vehicles can be used	• If the site is in an area with a high water table, drums can be staged on pallets, flatbed trucks, or in diked, elevated areas to prevent contact with water
DRUM OPENING	**CONSOLIDATION/RECONTAINERIZATION**	**INTERIM STORAGE AND TRANSPORTATION**
• Drum opening area should be diked and lined, particularly in an area with a high water table	• High water table may limit access of vacuum equipment and box trailers; skid-mounted units may be better suited than vacuum trucks	• Drums stored temporarily onsite should not be in contact with standing water; if the water table is high, construct the storage area on the highest ground possible; build dikes and diversions to control and collect runoff and improve drainage; use sump pumps to remove standing water; store drums on pallets.

TABLE 1E. ENGINEERING FEASIBILITY AND EFFECTIVENESS OF VARIOUS DRUM HANDLING METHODS

DRUM INTEGRITY		
LOCATION AND INVENTORY	EXCAVATION	DRUM STAGING
• If buried drums are leaking, it may be difficult to distinguish between drums and the plume using the following geophysical techniques: electromagnetic conductivity, electrical resistivity, and ground-penetrating radar; magnetometry and metal detectors should be used to confirm location of drums • If poor drum integrity is encountered during the inventory of drums, the following precautions may be needed: (1) staging of drums for random sampling; (2) using remotely operated drum opening equipment; (3) using air monitoring equipment extensively to monitor worker safety	• Corroded or leaking drums may require immediate overpacking or waste transfer prior to excavation; where the grappler is available it may be possible to risk rupture of the drum to protect worker safety • Use of the grappler is preferred for overpacking; forklift trucks equipped with grabbers can be used but require manual assistance, which jeopardizes worker safety • Equipment adaptations such as the use of morman bars to cover the bucket teeth or wide canvas slings that can be wrapped around a drum can minimize drum ruptures • Drums should be excavated and removed one at a time, especially if integrity is questionable • Small excavation equipment (with plexiglas shields) such as front-end loaders and bobcats can be used if drum integrity is good and hazard is low	• Overpack or transfer the contents of drums with poor integrity; waste transfer requires use of explosion- and acid-proof pumps; overpacking should preferably be done using the grappler; forklift trucks can also be used but require manual assistance, which can jeopardize worker safety

(continued)

TABLE 1E. (continued)

DRUM INTEGRITY		
DRUM OPENING	CONSOLIDATION/RECONTAINERIZATION	INTERIM STORAGE AND TRANSPORTATION
• All drums with poor integrity should be overpacked or their contents transferred prior to opening • The drum opening area should be lined and contained with dikes or berms; spill containment pans can also be placed under the drums	• Waste containers for offsite transport must meet DOT approval • Fibre drums are suitable for onsite incineration	• Drums approved for shipment must have good integrity; no signs of corrosion, bulging, etc.

TABLE 1F. ENGINEERING FEASIBILITY AND EFFECTIVENESS OF VARIOUS DRUM HANDLING METHODS

HAZARD/TOXICITY

LOCATION AND INVENTORY	**EXCAVATION**	**DRUM STAGING**
• If explosives or shock-sensitive drums are buried close to the surface, geophysical surveying using a vehicle-mounted instrument should not be undertaken; surveying may be limited to station-by-station monitoring • Suspected explosives or shock-sensitive drums should only be sampled remotely, and precautions should be taken to prevent a chain reaction in the event of a fire or explosion; if highly hazardous wastes are being sampled as part of the drum inventory, adequate spacing should be provided for emergency evacuation	• Radioactive wastes should be overpacked before excavating • Explosive and shock-sensitive wastes should be handled remotely wherever possible • Critically over-pressurized drums should be relieved remotely prior to excavating • Gas cylinders should be excavated cautiously, avoiding dragging or striking them • Potentially explosive or flammable wastes require use of non-sparking buckets and tools	• A grappler should be used for staging explosive- and shock-sensitive materials • Front-end loaders, bobcats, and forklift trucks can be used for onsite transfer and staging of wastes that are not highly hazardous • Stage radioactive and explosive materials in separate fenced areas • Stage gas cylinders in cool, shaded areas
DRUM OPENING	**CONSOLIDATION/RECONTAINERIZATION**	**INTERIM STORAGE AND TRANSPORTATION**
• Explosive and shock sensitive drums should be opened remotely, in a controlled area. The opening area should be physically separate from other working areas to avoid a chain reaction in the event of a fire or explosion	• Compatibility testing is required on all drums to determine which materials can be safely bulked • Vacuum trucks used for transporting liquids should be dedicated as much as possible to hauling one specific type of waste. This practice will minimize decontamination costs	• Incompatible waste types must be segregated during interim storage, using dikes and berms, and cannot be transported together

(continued)

TABLE 1F. (continued)

HAZARD/TOXICITY		
DRUM OPENING (continued)	**CONSOLIDATION/RECONTAINERIZATION** (continued)	**INTERIM STORAGE AND TRANSPORTATION** (continued)
• A remote drum opener is recommended for all hazardous or highly toxic wastes • Where manual drum opening tools are used, they should be nonsparking	• The lining or coating of vacuum cylinders must be compatible with specific waste types • Highly toxic/hazardous wastes should not be bulked with other materials where this will create an off-specification lot unsuitable for treatment/disposal • Certain wastes may require onsite pretreatment to make them acceptable for transport (e.g., solidification of sludges, neutralization, reduction of flash point) • In some instances, incompatible waste types (e.g., acids and bases) can be combined onsite. This must be done in a controlled environment (e.g., reaction tank)	• Special precautions are required for interim storage of some highly hazardous wastes (e.g., storage of explosives in fences areas; gas cylinders in cool shaded areas; reactive and explosive waste away from buildings)

TABLE 2. MAJOR ELEMENTS OF A SITE-SPECIFIC SAFETY PLAN

Major Element	Specific Considerations	Comments
Applicability	• site personnel • contractors • government agencies • visitors	
Responsibilities	• definition of roles • organization hierarchy • site supervision • government liaison • safety supervision • public relations responsibilities	Accommodate rotating supervisory personnel
Site Description	• define contaminant boundaries • define services, materials, and equipment within hot, transition, and clean zones	Consider space constraints, equipment transportation access, weather variables, security, and emergency response
Levels of Protection	• describe protective clothing and respiratory gear, equipment operators, and ancillary personnel	Consider exposure potential; job function; work stations by zone; level of site activity Allow for modifications and input from air monitoring results
Air Monitoring	• types of equipment by zone • procedures for monitoring during specific activities • offsite monitoring	Consider instrument selectivity & sensitivity; monitoring location; frequency; duration; recordkeeping; worst case scenarios
Personnel/Equipment Decontamination	• procedures for specific types of contaminants • sequence of procedures • manpower support	Consider reuse and storage of gear; wet/dry decontamination; discharge of contaminated wash water; frequency of use

(continued)

TABLE 2. (continued)

Major Element	Specific Considerations	Comments
Operations safety	• equipment operation • use of specially adapted equipment/tools for safe handling of drums • health monitoring and first aid • weather conditions • incident logs • safety meeting • buddy system • procedures and protocols to minimize potential for reactions, fires, explosions, etc.	
Emergency Evacuation	• procedures for onsite personnel and public • levels of response • notification procedures • communications • rescue techniques • emergency transportation	Consider worst case and likely events

Adapted from Buecker and Bradford, 1982 with permission of Hazardous Materials Control Research Institute, Silver Spring, MD.

TABLE 3. SAFETY PRECAUTIONS FOR DRUM HANDLING

Drum Handling Activity	Potential Safety Hazard	Safety Precautions
Locating and Inventory of Drums	Unknown location and contents of drums can lead to unsuspected hazards	• Carefully review background data pertaining to the location and types of wastes onsite. • Conduct soil and groundwater sampling only after the geophysical survey is completed to minimize the possibility of puncturing drums • During the random sampling of drums, which may be required for an inventory, spacing between drums should be adequate to allow for emergency evacuation if needed • Use remotely operated, nonsparking tools for random sampling whenever possible • Use direct-reading, air monitoring equipment to detect hot spots where contamination may pose a risk to worker safety
Determining Drum Integrity	The process of visual inspections requires close contact with drums of unknown content	• Approach drums cautiously, relying on air monitoring equipment to indicate levels of hazards that require withdrawal from the working area or use of additional safety equipment • Any drum that is critically swollen should not be approached; it should be isolated using a barricade until the pressure can be relieved remotely • Use of the grappler or other remotely operated equipment can eliminate the need for determining drum integrity prior to excavation provided rupture of the drum will not result in fire or unacceptable environmental impact
Drum Excavation and Handling	Exposure to toxic/hazardous vapors, rupture of drums	• Where buried drums are suspected, conduct a geophysical survey before using any construction equipment in order to minimize the possibility of rupture • Use the drum grappler where possible and cost-effective to minimize close contact with the drums • If the grappler is not available, pump or overpack drums of poor integrity prior to excavation • Ground equipment prior to transferring wastes to new drum

(continued)

TABLE 3. (continued)

DRUM HANDLING ACTIVITY	POTENTIAL SAFETY HAZARD	SAFETY PRECAUTIONS
Drum Excavation and Handling (continued)		• Use nonsparking hand tools and nonsparking bucket teeth on excavation equipment • Where slings, yokes, or other accessories must be used, workers should back away from the work area after attaching the accessory and before the drum is lifted • Critically swollen drums should not be handled until pressure can be relieved • Use plexiglas shields on vehicle cabs • Use "morman bars," which fit over the teeth of excavation buckets, to prevent drum puncture • Where ionizing levels of radiation are detected, the safety officer should be contacted; generally, the drum should be overpacked and isolated promptly • Gas cylinders should not be dragged during handling • Where explosive or shock-sensitive material is suspected, every effort should be made to handle the drum remotely • Use direct-reading, air monitoring equipment when in close proximity to drums to detect any hot spots
Drum Staging and Opening	Release of toxic, hazardous vapors, rupture of drums	• Stage gas cylinders in a cool, shaded area • Stage potentially explosive or shock-sensitive wastes in a diked, fenced area • Use remote drum opening methods where drums are unsound • Conduct remotely operated drum opening from behind a barricade or behind a plexiglas shield if backhoe-mounted puncture is being used • Isolate drum opening from staging and other activities if possible to prevent a chain reaction if an explosion or reaction does occur • If drum opening cannot be isolated from staging, drums should be staged so as to (1) minimize the possibility of chain reactions in the event of a fire or explosion and (2) provide adequate space for emergency evacuation

(continued)

TABLE 3. (continued)

DRUM HANDLING ACTIVITY	POTENTIAL SAFETY HAZARD	SAFETY PRECAUTIONS
Drum Staging and Opening (continued)		• Use only nonsparking hand tools if drums are to be opened manually • Remotely relieve the pressure of critically swollen drums before opening • Clean up spills promptly to minimize mixing of incompatible materials
Consolidation and Recontainerization	Mixing of incompatible wastes	• Perform onsite compatibility testing on all drums • Segregate wastes according to compatibility class following compatibility testing • Clean up spills promptly to avoid mixing of incompatible wastes • Intentional mixing of incompatible wastes such as acids and bases should be performed under controlled conditions in a reaction tank where temperature and vapor release can be monitored • Monitor for incompatible reactions during consolidation using direct-reading air monitoring equipment
Interim Storage and Transportation	Mixing of incompatible wastes	• Segregate incompatible wastes using dikes during interim storage • Maintain a weekly inspection schedule • Allow adequate aisle space between drums to allow rapid exit of workers in case of emergency • Keep explosives and gas cylinders in a cool, shaded or roofed area • Prevent contact of water reactive wastes with water • Clean up spills or leaks promptly • Have fire fighting equipment readily available within the storage area • Ensure adherence to DOT regulations regarding transport of incompatible wastes and drum integrity

TABLE 4. MEASURES FOR MINIMIZING ENVIRONMENTAL RELEASES DURING DRUM HANDLING

POTENTIAL ENVIRONMENTAL PROBLEM	PREVENTIVE MEASURES
Groundwater Contamination	• Construct a system of dikes and trenches around the site or around specific work areas to improve site drainage and minimize runoff • Where groundwater is an important drinking water source, it may be necessary to hydrologically isolate the work area using well-point dewatering. (Limited to highly sensitive environments) • Construct a concrete or asphalt pad with gravity collection system and sump for equipment decontamination • Use liners to prevent leaching of spilled material into groundwater during drum handling and drum opening, use spill containment pans during drum opening • Use sorbents or vacuum equipment throughout the operation to clean up spills promptly • Maintain overpacks at strategic locations in work areas and on the access road to be used for prompt cleanup of spills • Locate temporary storage area on the highest ground area available; install an impervious liner in the storage area and a dike around the perimeter of the area; utilize a sump pump to promptly remove spills and rainwater from the storage area for proper handling • Promptly overpack or transfer the contents of leaking drums prior to excavation in order to prevent ruptures.

(continued)

TABLE 4. (continued)

POTENTIAL ENVIRONMENTAL PROBLEM	PREVENTIVE MEASURES
Surface Water Contamination	• Construct dikes around the drum handling and storage areas • Construct a holding pond downslope of the site to contain contaminated runoff • Use sorbents or vacuum equipment throughout the operation to catch spills as they occur • Design the dikes for temporary storage area to contain a minimum of 10 percent of the total waste volume; ensure that holding capacity of storage area is not exceeded by utilizing a sump pump to promptly remove spills and rainwater
Air Pollution	• Avoid uncontrolled mixing of incompatible wastes by (1) handling only one drum at a time during excavation and (2) isolating drum opening operation from staging and working areas • Avoid dragging or striking gas cylinders • Promptly reseal drums following sampling • Promptly overpack or transfer the contents of any drum that is leaking or prone to rupture or leaking • Use vacuum units that are equipped with vapor scrubbers • Where incompatible wastes are intentionally mixed (i.e., acids and bases for neutralization) in a "compatibility chamber" or tank, releases of vapors can be minimized by covering the tank • Use small laboratory scrubbers during drum opening.

(Continued)

TABLE 4. (continued)

POTENTIAL ENVIRONMENTAL PROBLEM	PREVENTIVE MEASURES
Fire Protection	• Use nonsparking hand tools, drum-opening tools, and explosion-proof pumps when handling flammable, explosive, or unknown waste • Avoid uncontrolled mixing of incompatible waste by (1) handling only one drum at a time, (2) pumping or overpacking drums with poor integrity, (3) isolating drum opening, and (4) conducting compatability testing of all drums • Use sand, foams, etc., to suppress small fires before they spread • Avoid dragging or striking gas cylinders • Avoid storage of explosives or reactive wastes in the vicinity of buildings • In a confined area, reduce concentration of explosives by venting to the atmosphere • Cover drums that are known to be water reactive • Properly ground equipment

SECTION 4

LOCATION, DETECTION, AND INVENTORY OF DRUMS

The activities described in this section are undertaken either as part of the preliminary assessment and the remedial investigation or during the immediate removal operation, as described in the National Contingency Plan (NCP). These activities include a review of background data, aerial photography, geophysical surveying, sampling, and an onsite inventory of drums. For drum handling, the objectives of these tasks are to locate and define the boundaries of buried and aboveground drums, assess the types and amounts of wastes and their potential hazard, and provide needed information to determine whether immediate or planned removal is warranted.

REVIEW OF BACKGROUND DATA

A review of background data is undertaken as part of the preliminary assessment. This activity can provide guidance on the site-specific safety plan, costs, equipment, and methods required for drum removal or source control measures, and can focus subsequent site investigation activities.

There are four basic types of information that can be obtained by reviewing background data: drum storage, handling, and disposal practices; waste characterization; hydrogeologic setting; and location of receptors.

A review of information on drum storage, handling, and disposal practices should focus on determining the following:

- Location of drums
- Number of drums
- Condition of drums (and expected condition in 1 to 2 years)
- Burial or aboveground storage of drums
- Handling of incompatible wastes during disposal
- Codisposal of drums with bulk wastes
- Nature of the drum disposal operation (whether drums were disposed of haphazardly or efforts were taken to prevent rupture or denting during disposal)

- Efforts taken to minimize corrosion (i.e., lining of trenches or cover for drums aboveground).

Although existing data on waste characterization are frequently sketchy, background data should be used to the extent possible to determine the physical state of the wastes (solids, liquids, or gases); broad waste categories (e.g., flammables, radioactives, or water reactives); and specific waste types (e.g., solvent still bottoms or paint sludges).

Information on the hydrogeological setting should be used to determine factors such as the elevation of the water table, direction rate, nature of groundwater flow, and the depth to bedrock. These factors can provide useful information on the probable condition of the drums, extent of groundwater plume, and site-specific conditions that may dictate the need for specific equipment types during drum handling.

Proximity to receptors can determine whether removal or remedial action is warranted and can dictate the need for specific precautions to protect sensitive environments or nearby populations.

Table 5 summarizes widely used sources of background information.

AERIAL PHOTOGRAPHY

Aerial photography is an effective and economic tool for gathering preliminary information on waste disposal sites and for locating drums. Use of aerial photographs can minimize the need for extensive remote sensing, excavation, and/or sampling by providing a general indication of the location of buried drums. Because maps of the site can be prepared before inspection, potential hazards for field personnel can be noted and minimized.

Aerial imagery refers to pictorial representations produced by electromagnetic radiation that is emitted or reflected from the earth and recorded by aircraft-mounted sensors. One type of aerial imagery is the photograph, the simplest, most common kind of imagery, which uses only the visible part of the electromagnetic spectrum. Three types of photographs are often used for gathering information on disposal sites. Oblique photos are taken at angles to the earth's surface and thus distort the scale of the picture (objects in the foreground are larger and objects in the background are smaller than actual size). Therefore, oblique photos are useful when scale is not important, such as when areas must be surveyed for suspicious dead vegetation, barren areas, or pits. High resolution photographs enable investigators to identify drums and other small-scale objects. Perpendicular photos, or stereophotos, which are taken from directly above the site so that there is little or no distortion, can be used in pairs to show the topography of the site in three dimensions.

The second type of aerial imagery uses wavelengths of light that are outside the visible spectrum. The three most common types of images are infrared, radar, and multispectral.

TABLE 5. SOURCES FOR BACKGROUND DATA RELATED TO DRUM HANDLING AND DISPOSAL

Drum Storage, Handling, and Disposal Practices	Waste Characteristics	Hydrogeologic Setting	Location of Receptors
Site owner/operator	Site records	Topographic maps	County Planning Agencies
Generators	• inventories • permits • manifests	USDA[2] soil surveys USDA[2] water supply papers	County and State Health Departments
Private citizens	Generator records	USGS[3] water resource maps	Zoning records
Site records, especially permits	REM/FIT[1] reports	Flood Insurance maps	State Departments of Natural Resources
Historic aerial photography	Monitoring/sampling data	Well drillers logs Property surveys	Local citizens groups Historical aerial photography
REM/FIT[1] reports		Climatological data REM/FIT[1] reports	REM/FIT[1] reports

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[1] REM/FIT - Remedial/Field Investigation Team

[2] USDA - United States Department of Agriculture

[3] USGS - United States Geological Survey

Infrared imagery indicates areas that are hotter or cooler than the general surroundings. This is useful, as drums leaking hazardous wastes may give off heat in continuing reactions, and areas of dead vegetation have different radiant heating (albedo) characteristics than vegetated areas.

Radar imagery uses side-looking radar to accentuate topographic relief without recording vegetation. This type of image would be especially useful for discovering covered trenches or pits that are camouflaged by dense vegetation.

Multispectral imagery refers to a series of images, each of which uses a different portion of the light spectrum. This type of imagery provides the greatest amount of data although it also takes the most time and skill to interpret. The cost involved in data acquisition and computer processing often makes this system cost-ineffective (JRB Associates, 1980).

Table 6 summarizes the important aspects of photographs and images in the discovery of drums and leaking wastes from drums.

Aerial photos and interpretative assistance for the eastern EPA regions are available from the Environmental Photographic Interpretation Center (EPIC) in Warrenton, Virginia. The Environmental Monitoring Systems Laboratory (EMSL) in Las Vegas, Nevada, offers similar services for the western EPA regions. These groups also provide technical support and film development for the EPA regions' Enviropod Systems. The Enviropod is a portable camera system that can be readily installed in aircraft.

EPIC's Imagery Analysis System (IAS), designed by Calma Corporation, is capable of rectifying photo-to-map scales for plotting points directly from imagery to a standard map. The system also determines the exact geocoordinates for an individual site and computes the area of a particular feature (Titus, 1981).

Trend analysis using sequential historic aerial photographs is another useful method for locating drums. Archival photographs taken after 1950 are available from the National Cartographic Information Center, USGS, Reston, Virginia, and from Earth Resource Observation System (EROS) Data Center, Sioux Falls, South Dakota. Photographs taken from about 1930 through 1950 are available from the National Archives in Washington, D.C. Generally, the requestor must specify the geographical coordinates (latitude and longitude) of the site. Standard orders for copies of photographs can generally be processed within 6 weeks (Holmes, 1980; JRB Associates, 1980). If there are gaps in the coverage, State archives and privately owned cartographic plots may provide the missing information.

Comparison of historic photographs over the span of time when operations took place at a given site can strongly suggest the location of drums. The following changes should be noted:

- Filled-in trenches

- Mounded soils or paved surfaces

TABLE 6. SUMMARY OF AERIAL IMAGERY AS A TOOL FOR LOCATING DRUMS

Type of Imagery	Type of Information Provided	Key Features to Look For	Comments
Oblique photos	Photographic view of sites	Dead vegetation, drums, and pits	Readily available and easy to interpret, but limited amount of information provided
Stereoscopic photos	Three-dimensional photographic view of sites	Same as oblique, plus drainage patterns, stunted vegetative growth, and unusual mounds or sinks	Readily available and can provide much more information than oblique photos but more difficult to interpret
Infrared images	Variations in surface temperature	Abnormal vegetative patterns, leachate plumes, anomalous hot or cool areas	Not as readily available on an appropriate scale as are photographs; much more difficult to interpret but can provide a great deal of information not available from photos
Radar images	Surface topography without vegetative cover	Drainage ways, surface impoundments, and pits	
Multispectral images	All of the above plus data from other specialized types of imagery	All of the above plus other specialized types of features	Generally not considered cost-effective

Source: JRB, 1980

- Changes in vegetation
- Disappearance of pits, quarries, or natural depressions
- Changes in traffic patterns.

The areas of concern are generally plotted on overlays to aerial photographs and analyzed for any changes that may have occurred over time.

GEOPHYSICAL SURVEYING

A number of surface geophysical techniques have been proven to be effective in resolving details of site conditions, locating buried drums, and defining the boundaries of leachate plumes. These techniques, and their applications and limitations, have been described extensively in the literature. A number of valuable references have been included in the reference list. The theory, applications, and limitations of these methods are briefly described in Table 7 and in the following subsections.

Metal Detection

Metal detectors respond to the high electrical conductivity of metal objects and can detect both ferrous and non-ferrous metals. The metal detector is a near-field device that can detect metal objects to a maximum of 2.4 to 3.7 meters (8-12 feet). The detection distance is generally much less, however, because of geological or cultural noise or the presence of the drums. The detection distance may be reduced to as low as 1.2 to 1.5 meters (4-5 feet) in areas containing buried drums. The major advantage of the metal detector is that it is inexpensive and easy to use. The hand-held models are lightweight, readily available, and easy to handle, but models are also available that can be vehicle mounted for continuous surveying. In addition to low sensitivity, a major disadvantage of the metal detector is the system's sensitivity to both iron oxides in the soil and conductive leachates. The presence of lateral metallic objects such as fences or cables limit the performance of most of the readily available, commercial models. However, special systems are available that can minimize these interferences (Sandness et. al., 1979; Ecology and Environment, 1981; Yaffe, 1980; Pease and James, 1981).

Magnetometry

A magnetometer responds to changes in the earth's magnetic field caused by the presence of ferrous objects. Unlike the metal detector, the magnetometer will not respond to nonferrous metals. Compared to the metal detector, the magnetometer can detect ferrous objects that are smaller and at a much greater distance to depths of 2 to 9 meters (10-30 feet). The increased sensitivity of this instrument makes it valuable for approximating drum density, boundaries of trenches containing drums, and drum location.

There are three types of magnetometers available: the proton precession, or total field magnetometer; the fluxgate gradiometer; and the

TABLE 7. SUMMARY OF GEOPHYSICAL SURVEY METHODS

Method	Principle of Operation	Features/Advantages	Disadvantages
Metal Detector	Induces an electromagnetic field around an object in response to radiation from a transmitter	• Widely available commercial equipment; lightweight • Vehicle-mounted systems are also available for operation in the continuous mode • Can be used among vegetation • Data can frequently be interpreted in the field • Can detect ferrous and nonferrous metals	• Low sensitivity; depth of detection is only 1.2 to 1.5 meters (4-5 feet) in areas where where drums are buried • Not suitable for nonmetallic objects • Most commercial models have limited use in locations with pipes, chain linked fences, etc., although special models that minimize these interferences are available • May be sensitive to the presence of iron oxides in soil and conductive fluids
Magnetometers	Measures minute changes in the earth's magnetic field induced by a buried ferromagnetic object		
- Proton Precession Magnetometer	Uses the precession of spinning protons or nuclei of the hydrogen atom in a sample of hydrocarbon fluid to measure total magnetic intensity	• Much more sensitive than the metal detector; can detect metal drums to depths of 3 meters (10 feet) or more • Can approximate boundaries of trenches containing buried drums • Low sensitivity to soil conditions • In simple cases data can be interpreted in the field	• Unsuitable for nonferrous objects • Generally limited to station-by-station measurements • Has limited use in locations with pipes, chain-link fences, etc., because it will respond to nearly all objects, making data interpretation very difficult
- Fluxgate gradiometer	Uses two sensors that balance out the effect of the earth's magnetic field. The existence of an external field such as a drum disturbs the flux balance and the voltage induced is proportional to the strength of the ambient field	• Virtually blind to interferences in the horizontal plane; can be used near (2m, or 7 ft) a chain-linked fence • Can approximate the boundaries of trenches containing buried drums • Low sensitivity to soil conditions	• Detects only ferromagnetic objects

(continued)

TABLE 7. (Continued)

Method	Principle of Operation	Features/Advantages	Disadvantages
-Fluxgate gradiometer (continued)		• Can be vehicle-operated or hand-towed, as conditions dictate • In simple cases, data can be interpreted in the field	
Ground-Penetrating Radar	Emits electromagnetic pulses into the ground and detects and records reflections from from subsurface objects	• Can detect plastic drums and leachate plumes • Provides approximate depth of burial and orientation of drums in the trench • Provides continuous survey data • Can be vehicle-operated or hand-towed as conditions warrant • Under certain conditions, can provide the greatest level of detail of all subsurface survey methods • Can penetrate concrete if no reinforcing bars are present • Can perform rapid exploratory work or can be hand-towed at slow speeds to provide detailed studies	• Performance is highly site-specific, affected by presence of cables, chain link fences, etc. • Not suitable for sites with heavy clay soils, high groundwater salt concentrations, or other materials that absorb electromagnetic energy • Limited use in vegetated areas • Detection of some drums can be masked by presence of drums above • Equipment is more difficult to set up and operate than metal detectors, magnetometers, or electromagnetic methods
Low Frequency Electromagnetics	Measures subsurface conductivities	• Detects wastes leaking from drums, approximates plume boundaries, and determines direction of plume flow • Continuous conductivity data can be obtained for depths ranging from 4.5 to 6 m (15-20 ft); measurements of 8 to 60 m (25-200 ft.) are possible in a station-by-station point survey • Most cost-effectively applied to lateral profiling at fixed depths	• Cannot always distinguish between drums and uncontainerized wastes • Performance is degraded by presence of buried pipes, cables, and fences; however, some interferences can be filtered during data processing • Data interpretation often requires computer processing

(continued)

TABLE 7. (Continued)

Method	Principle of Operation	Features/Advantages	Disadvantages
Low Frequency Electromagnetics (continued)		• Combination of continuous and depth profiling can provide 3-D coverage • Raw data can be approximated in the field. Further data processing can be used for 3-D plotting, plotting of contours, filtering of cultural features.	
Electrical Resistivity	Based upon the conduction of electric current through subsurface materials to measure changes in bulk electrical resistivity (reciprocal of conduction)		
- Lateral Profiling		• Detects materials leaking from drums and determines the extent of contamination • Equipment lightweight and portable	• Limited ability to detect nonconductive pollutants • Data interpretation may be difficult, especially if there are lateral variations in stratigraphy • Performance is degraded by presence of pipes, fences, etc. • Technique is slow and costly
- Depth Profiling		• Determines change in contamination with depth • Provides more detailed sounding than is achievable with EM conductivity	• Limited ability to detect nonconductive pollutants • Technique is slower than depth profiling using EM method

(continued)

TABLE 7. (Continued)

Method	Principle of Operation	Features/Advantages	Disadvantages
Seismic Refraction		• Can be used to determine depth of buried drums and bedrock	• Method not well tested for drum detection • Depth of penetration varies with energy source • Data interpretation may be difficult if stratigraphy is complex • Requires access road for vehicles and cannot be operated in the continuous mode

Sources: Ecology and Environment, 1981; Sandness, et. al., 1979; Benson and Glaccum, 1980; Lord, Tyagi, and Koerner, 1981; Evans, Bensen and Rizzo, 1982; Kolmer 1981; Horton, 1981; Pease and James, 1981; Yaffe, Cichowicz, and Stoller, 1980.

cesium vapor magnetometer. The cesium vapor magnetometer is a relatively new device that is expensive to use and currently has little practical application for hazardous waste investigations. The fluxgate gradiometer is often preferred over the proton precession magnetometer because the gradiometer is less sensitive to background noise. Gradiometers are available with a neutral dead zone in the horizontal plane that blinds the instrument to potential lateral interferences such as metal fences, cables, or passing cars. This instrument can be used as close as 2 meters (7 feet) to a chain linked fence. In addition, the gradiometer can be vehicle-mounted for continuous profiling, while the proton precession magnetometer is generally limited to station-by-station measurements. Of all the geophysical surveying tools, the gradiometer produces the least amount of cultural (e.g., pipes, fences, passing cars) and subsurface interferences (Benson and Glaccum, 1980; Sandness et al., 1979; Ecology and Environment, 1981; Kolmer, 1981; Lord, Tyagi, and Koerner, 1981; Evans, Benson, and Rizzo, 1982).

Electromagnetic Conductivity

Low frequency electromagnetics (EM) provide a measure of subsurface conductivities. These conductivities are a function of the basic soil/rock matrix, its pore space, and the groundwater or leachate that permeates the matrix. In most instances the conductivity of the pore fluid will dominate the measurement. The EM method can be used effectively for mapping hydrogeology of the site and conductive leachate plumes and their direction of flow as well as for locating and defining the boundaries of buried drums. In some cases, however, it may be difficult to distinguish between a conductive plume and buried drums.

EM methods can be used either for continuous profiling at shallow depths of 4.5 to 6.0 meters (15-20 feet) or for station-by-station profiling at depths of 7.6 to 60 meters (25-200 feet). EM measurements are usually, and most economically, made by traversing the site at a fixed depth. However, sounding data can also be obtained to assess vertical hydrogeologic changes. A combination of continuous and depth profiling can provide three dimensional coverage, although this requires complex data processing. The performance of EM methods can be degraded by the presence of buried pipes, cables, and fences (Ecology and Environment, 1981; Lord, Tyagi, and Koerner, 1981; Benson and Glaccum, 1980; Evans, Benson, and Rizzo, 1982).

Ground-Penetrating Radar

The response of ground-penetrating radar (GPR) is caused by radar wave reflections from interfaces of materials having different complex dielectric constants. The reflections are often associated with natural hydrogeologic conditions such as bedding, fractures, moisture and clay content, and voids, as well as man-made objects such as buried drums and surface cultural features (e.g., fences, cables). GPR offers the highest level of detail of the geophysical survey methods because of the high frequency energy that is used. However, it is also subject to several interferences. Penetration depths of commercial systems vary from less than 1 to more than 20 meters (0.3-60 feet) depending upon the frequency, the dielectric constant of the medium and the constitutive electromagnetic parameters of the soil. The depth of penetration may be particularly shallow where clay soils or conductive groundwater are present. Performance of GPR is highly site-specific, but under favorable site conditions it can be used to define plume boundaries, locate metallic and nonmetallic drums, and approximate drum density, depth, and the boundaries of buried trenches.

Radar performance is also frequency sensitive, and optimum antenna frequency must be selected based on the depth of penetration and the resolution required. Low-frequency antennas provide better penetration while high-frequency antennas provide better detail (Horton, 1981; Benson and Glaccum, 1979; Benson and Glaccum, 1980; Kolmer, 1981; Lord, Tyadi, and Koerner, 1981).

Electrical Resistivity

Electrical resistivity is somewhat analogous to EM. In both cases, the operation depends on the fact that any subsurface variation in conductivity alters the form of current flow within the earth. However, electrical resistivity measures changes in bulk electrical resistivity rather than conductivity (the reciprocal). Unlike EM, resistivity requires direct electrical contact with the earth via four probes driven into the soil. This makes continuous surveying impossible and station-by-station methods slow in comparison to EM. Either lateral or depth profiling can be obtained depending upon the electrode configuration. Although electrical resistivity is slower and more costly than EM, it generally provides more detailed sounding data. The two methods can be effectively used together for delineating subsurface geology and developing three dimensional profiles of plumes. As with the EM method, resistivity is subject to cultural interferences and may not always distinguish between drums and conductive plumes (Horton, Morey, Isaacson, and Beers, 1981, Lord, Tyadi, and Koerner, 1981; Evans, Benson, and Rizzo, 1982). In addition, data interpretation in lateral profiling can be very difficult if radical changes in topography are not adequately accounted for by the electrode spacing and if there are lateral variations in stratigraphy (Pease and James, 1981).

Seismic Refraction

Seismic refraction traditionally has determined the depth and thickness of geologic strata by using elastic waves transmitted into the ground by an energy source such as a hammer blow on a steel plate. The waves travel through different subsurface strata at different velocities and the refracted waves are detected by small seismometers (Yaffe, Cichowicz, and Stoller, 1980). Although not widely used in locating hazardous wastes, refraction methods have the potential for locating and defining the boundaries of drum burial pits and trenches (Evans, Benson, and Rizzo, 1982; Pease and James, 1981). A major disadvantage to seismic refraction is the difficulty in interpreting data in areas with complex stratigraphy or where there is no sharp contrast in velocity (Yaffe, Cichowicz, and Stoller, 1980; Pease and James, 1981).

Method Selection and Implementation

There are obvious advantages and limitations to each of the geophysical survey methods discussed above. Before initiating a geophysical survey it is necessary to clearly establish the objectives of the survey, whether it be to locate drums, to estimate their number and the boundaries of the trench, or to determine the extent to which they are leaking. If drum location is all that is required, magnetometry, or, in some instances, metal detection will be adequate. If it is necessary to estimate the number of drums and determine the extent of leachate migration, EM, GPR, and magnetometry may be needed in combination.

Site characteristics should also be an important consideration in selecting the most appropriate survey methods since a number of site-specific factors can affect method performance. The presence of cultural features can affect the performance of several geophysical techniques. GPR is poorly suited for surveying where soils have a high clay content. The presence of saline groundwater effects the performance of GPR, EM, and electrical resistivity. Other examples of the effects of site-specific factors on performance are summarized in Table 7.

Difficulty of data interpretation should also be considered when selecting the appropriate geophysical surveying equipment, particularly where immediate results are needed or where financial resources are very limited. Metal detection and magnetometry will frequently provide useful information in the field, although further data processing is often recommended for such things as spatial correction, filtering, and plotting parallel sets of data. GPR, electromagnetics, and resistivity usually require data processing, although raw data may be of value as an initial assessment tool depending upon the complexity of the site.

Costs are influenced by numerous factors, some of which cannot be predicted at the outset of the survey. Some of the major variables influencing costs include:

- Use of instruments that are towed by a vehicle or are handheld. Surveys are likely to be done by hand if the drums are close to the surface and there is a risk of rupture or if the site is in a marshy or highly irregular terrain.

- The type of data needed, particularly the adequacy of determining only the general location of groups of drums or the necessity of approximating the boundaries of trenches and the number of drums.

- Degree of site preparation. Vegetative cover interferes with many of the geophysical survey methods, and sites must often be cleared before surveying.

- Degree of data interpretation required, which is determined not only by choice of survey method but also by the depth of drums and the need to filter interferences such as cultural features and surface irregularities.

- Previously unpredicted subsurface anomalies, or interferences, which degrade performance of a particular survey method, requiring a change to another method.

Case Study Applications of Geophysics

Three case studies are briefly discussed below to illustrate the application of geophysical survey methods for drum detection and plume delineation.

Figure 1 shows a three dimensional representation of a 10 hectare (25 acre) waste disposal area developed from lateral and depth EM profiling. The results clearly defined the perimeter and maximum depth of the wastes. GPR was later used to further confirm the perimeter of the contamination. However, neither EM or GPR could confirm whether the buried material was bulk-dumped or disposed of in drums. Followup magnetometry profiles indicated that only a few drums were present within the large disposal area. Before conducting the geophysical survey, six monitoring wells had been installed at the site in an effort to locate the wastes. As shown in Figure 1, all of the wells missed the target area. By conducting the geophysical survey first, there would have been better guidance on the appropriate location of monitoring wells (Benson, Glaccum, and Beam, 1981; Evans, Benson, and Rizzo, 1982).

Benson and Glaccum (1980) reported on a site investigation in which ground-penetrating radar, metal detection, magnetometry, and electromagnetics were used successfully in detecting drums. Electromagnetics, magnetometery, and metal detection profiles all showed significant anomalies over a trench indicating large amounts of conductive metal material. The combination of responses indicated the presence of 55-gallon steel drums. The magnetic data, when plotted as continuous lines (Figure 2), also provided a semi-quantitative measure of the spatial location and quantity of steel drums present. The metal detector provided a sharper response at the edge of the trench, resulting in a better spatial definition of the drum boundaries. GPR clearly showed a trench cut into the soil profile and indicated the bottom of the trench at 2.1 meters (7 feet). This combination of methods provided the investigators with increased confidence in determining drum quantity and location.

At the Picillo Farms site in Coventry, Rhode Island, a combination of metal detection and GPR data were used to determine the dimension of trenches containing buried drums and to estimate their number. Figure 3 shows a comparison of the trench boundaries as detected by GPR and metal detection. The boundaries of two of the three trenches were detected to be similar, though not overlapping, by the two methods. The contractor in this instance had more confidence in the GPR data. A third trench was detected by GPR but

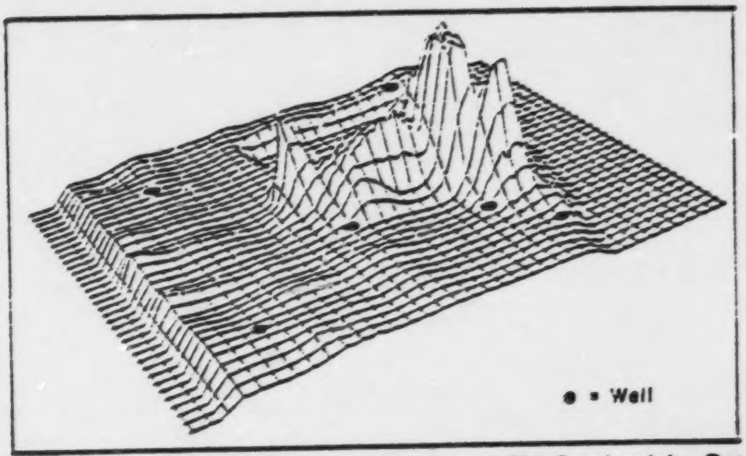


Figure 1. Three Dimensional Representation of EM Conductivity Data Showing Buried Hazardous Materials
(Benson, Glaccum, and Beam, 1981. Figures originally printed in the Proceedings of The National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981. Available from Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, MD 20910.)

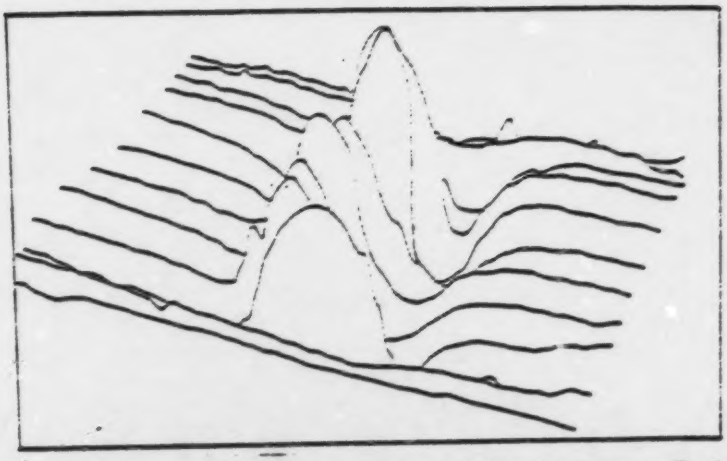


Figure 2. Continuous, Parallel Lines of Magnetic Gradient over a Buried Drum Site Defining the Location and Lateral Limits of Drums
(Benson and Glaccum, 1980. Figure originally printed in the Proceedings of The National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980. Available from Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, MD 20910.)

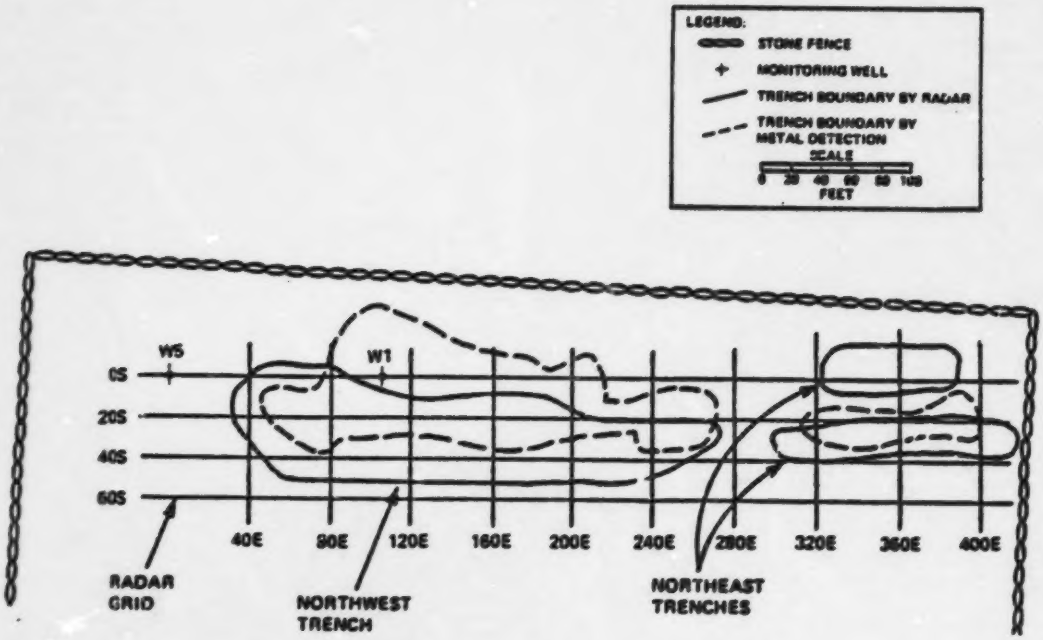

LEGEND:
STONE FENCE
MONITORING WELL
TRENCH BOUNDARY BY RADAR
TRENCH BOUNDARY BY METAL DETECTION
SCALE
0 20 40 60 80 100
FEET
W5
W1
0S
20S
40S
60S
40E
80E
120E
160E
200E
240E
280E
320E
360E
400E
RADAR GRID
NORTHWEST TRENCH
NORTHEAST TRENCHES

Figure 3. Comparison of Ground Penetrating Radar and Metal Detection Survey Results for Drum Containing Trenches Located at Picillo Farms, Coventry, RI
(Source: Pease et al., 1981)

not by metal detection. However, the GPR data provided incomplete areal coverage for the western trench, and the data were supplemented by data from the metal detection survey. The GPR data also provided some qualitative information on the way drums were placed in the trench (randomly stacked and clustered), but were unable to indicate the bottom of the trenches because the upper drums masked what was beneath (Pease et al., 1980).

SAMPLING

Sampling efforts undertaken during remedial investigations can vary widely in nature and complexity. When conducted prior to an immediate removal operation for drums aboveground, sampling is generally limited to a random sampling of the drums. On the other hand, if source control measures are anticipated, a comprehensive groundwater sampling program may be required.

Drum Sampling

Drum sampling undertaken prior to immediate removal, or initial removal measures, is generally limited to a random sampling of drums stored aboveground. This allows a gross categorization of the types of waste onsite and this information is then used to prepare bid documents, cost estimates for cleanup, feasibility studies, and design reports. This random sampling effort should not be confused with the more comprehensive sampling of every drum, which is generally required as part of the drum consolidation protocol (see Section 9). Procedures for opening and sampling drums are discussed in Sections 8 and 9, respectively.

A determination of the number of drums to be sampled should be based on the total number of drums, costs, requirements for restaging the drums before they can be safely sampled, and an observation on the variability of waste types based on background data and visual inspections. Depending on these variables, random sampling of drums may involve 5 to 25 percent of the drums. In an effort to obtain a representative, random sample, drums should be selected for sampling based on markings, labels, codes, type of drum, and physical location relative to other drums onsite.

Soil Sampling

Soil sampling is frequently conducted to obtain additional information regarding drum location, depth of burial, condition of drums, and types of wastes present.

Sampling points are selected based on information obtained from background data pertaining to drum disposal practices, aerial photography, and the results of geophysical surveys. If subsurface burial is suspected, it is recommended that a geophysical survey precede soil sampling to minimize the potential for rupturing drums or exposing field personnel to highly toxic pockets of waste. Direct-reading air monitoring equipment should be used during soil sampling to warn field personnel of potential hazards. Use of this equipment is discussed in Section 6.

The sampling points can be selected using one of three approaches: random sampling pattern, grid pattern, or grid pattern in which several samples from within the grid area are combined to give average concentrations. The selection of subsurface soil sampling equipment depends on the accuracy of sampling data needed, the types of soil and subsurface materials encountered, and the depth of sampling required. A widely used technique for rapid location of buried drums is to use a backhoe to excavate shallow test pits that are monitored for volatile organic hydrocarbons. An organic vapor analyzer (see photoionization and flame ionization detectors under Section 7), equipped with a probe for remote sensing, is lowered into the test pit and the concentration of volatile organics is measured. The results can be mapped on overlays of the site to determine vertical and horizontal concentration profiles that can suggest areas of buried drums. The advantages to this method is its quickness compared to other soil sampling techniques and its lowered risk for field personnel through the use of a backhoe, rather than hand tools, to excavate the test pits.

Various types of hand-operated soil sampling equipment are also available. Applications and use of this equipment is discussed in detail in Sampling and Sampling Procedures for Hazardous Waste Streams (de Vera, Simmons, Stevens, and Storm, 1980). Table 8 briefly summarizes the capabilities and limitations of hand-operated, soil sampling equipment.

Groundwater Sampling

Groundwater sampling also may be required as part of a remedial investigation, particularly if source control options are being considered. Considerable guidance is available on groundwater monitoring techniques and analysis and interpretation of data. Useful references include the following:

- Groundwater Monitoring Guidance for Owners and Operators of Interim Status Facilities (U.S. EPA, 1983a)
- Procedures Manual for Groundwater Monitoring at Solid Waste Disposal Facilities (U.S. EPA, 1980b)
- Aquifer Contamination and Protection (Jackson, 1980).

PREPARING A DRUM INVENTORY

After completing the site investigation activities, it is usually possible to prepare a drum inventory, which provides an estimate of the number and type of drums on a site. The drum inventory can vary considerably in detail depending on the information gathered during the site investigation and whether the drums are buried or aboveground. Table 9 shows the format used to inventory drums at the Keefe Environmental Services Site where drums and other containers had been stored aboveground (U.S. EPA, 1982c).

Considerable detail was available for this site, and it was possible to determine the number of specific types of drums and containers at various locations at the site. This information was valuable to potential subcontractors in determining equipment needs and drum removal costs. In addition, using the data derived from the random sampling effort, it was possible to develop a gross categorization of waste types found at the site (Table 10).

Estimating the number of buried drums at a site usually requires a reliance on geophysical testing methods and background or historic data. At the Picillo Farm Site in Coventry, Rhode Island, the number of buried drums was estimated using a combination of geophysical surveying methods. The procedure used located the trenches and estimated their dimensions through a combination of metal detection, GPR, limited excavation, and seismic refraction. Two nominal trench depths of 4.3 to 6.7 meters (14-22 feet) were used to bracket the range determined by remote sensing and direct excavation. Two drum densities also were used to estimate the number of drums: 50 percent and 90 percent. An estimated range of the number of drums was then prepared, as shown in Table 11.

TABLE 8. APPLICABILITY AND LIMITATION OF VARIOUS SOIL SAMPLING METHODS

EQUIPMENT	APPLICATION	MAJOR LIMITATIONS
Shovel and scoop	Soil samples up to 8 cm (3 in) deep	• Suitable for surface samples only • Identical mass sample units for a composite sample are difficult to collect
Sampling trier	Core sampling to depths of 0.8 to 0.9 m (2.5-3 feet)	• Cannot be used in soils with high stone and gravel content
Hand auger	Soil samples to depths of 1.2 to 1.5 m (4-5 feet)	• Mixes soils so that no distinction can be made between samples collected near the surface or toward the bottom
Hand driven, split spoon sampler	Relatively undisturbed core samples	• Depth depends on soil type and the number of sampling rod sections available for the split spoon
Hand-driven hollow stem	Undisturbed core samples to depths of 4.9 m (16 feet)	• Suitability limited in rocky or wet soils

Source: de Vera, et al., 1980

TABLE 9. DRUM INVENTORY FORMAT
KEEFE ENVIRONMENTAL SERVICES SITE, EPPING, N.H.

Area	Lab Packs (Actually Seen)	Overpacks	Poly-Liner/ Poly-Drum	Ring Top	Bung Top	Ring and Bung Top	Five Gallon Pails	Total Liquid	Total Solid	Total Empties	TOTAL ALL DRUM
A											
B											
C											
Subtotal											

Adapted from U.S. EPA., 1982c

TABLE 10. CATEGORIZATION OF WASTE TYPES AT THE KEEFE ENVIRONMENTAL SERVICES SITE BASED ON RANDOM SAMPLING OF DRUMS*

Waste Type	Percent of Total Drums
Solids	19
Acids	18
Nonchlorinated Solvents	14
Resins	9
Aqueous Waste	7
Alkali Waste	7
Cyanide Waste	6
Waste Oil	6
Paint Waste	5
Sludges	4
Chlorinated Solvents	2
Glycols	2
Empty	1
PCB Oil	1

*Based on a random sampling of 20 to 25 percent of drums. Total adds to 101 percent due to rounding.

Source: U.S. EPA, 1982c

TABLE 11. ESTIMATED NUMBER OF BURIED DRUMS AT PICILLO FARMS, RI, BASED ON EXTRAPOLATION OF BEST AVAILABLE DATA

Trench Location	Maximum Drum Density		Drums Randomly Stacked	
	d = 14 ft	d = 22 ft	d = 14 ft	d = 22 ft
Northwest	14,800	22,400	8,200	12,400
West	13,500	20,200	7,500	11,200
South	1,700	2,100	1,000	1,200
Total	30,000	44,700	16,700	24,800

Notes: d = nominal trench depth

Random stacking indicated by results of excavation of Northwest Trenches, approximated by 50 percent drums, 50 percent earth by volume in trench below 2-foot cover and assumed trench geometry.

Drums are assumed to be uncrushed, 55-gallon drums.

Source: Pease et al., 1980.

SECTION 5

SITE PREPARATION

Before remedial or removal actions can begin, the site must be prepared to improve the safety and efficiency of drum handling, and the appropriate support facilities must be constructed or installed. The nature and extent of site preparation varies widely from site to site depending on the hazard of the wastes, the environmental sensitivity of the site, and the location of the site with respect to surrounding populations.

SITE ACCESS IMPROVEMENTS

Site roads are required to provide access to all apparent drum disposal areas as well as to staging, consolidation, and decontamination areas. Roads must be suitable for transport of all proposed vehicles under all possible weather conditions. At some sites it may be necessary to construct edge gutters that drain into sumps along the access roads in order to collect spills and contaminated runoff.

Where drums have been disposed of in heavily wooded or vegetated areas, clearing and grubbing may be necessary to provide access for drum handling and construction equipment or to provide spacing required for such activities as staging and opening. This work may include removal of vegetative cover, tree-cutting and excavation, and removal of tree trunks and roots. Although conventional construction equipment can be used for clearing and grubbing, several safety precautions should be taken. Geophysical testing may be required prior to excavation to determine the presence of drums or buried pipes that could be easily ruptured by excavation equipment. Plexiglas safety shields should be used on all vehicles to protect equipment operators from explosive or shock-sensitive wastes buried near the surface.

At sites with buried drums, access improvements may involve excavation of an access trench near the actual drum trench to facilitate drum removal. The access trench should have gradual side slopes that allow drum transport traffic in and out without tipping waste containers.

SUPPORT FACILITIES AND STRUCTURES

There are a number of support facilities or specially designated operating areas that must be constructed or installed prior to cleanup. These may include:

- Staging areas
- Drum opening area
- Waste consolidation/loading areas
- Interim storage areas
- Equipment and personnel decontamination areas
- Mobile laboratory
- Command post and administration area
- Emergency medical facilities
- Equipment maintenance area.

The site layout should be such that there is a minimum-safe travel distance between the disposal and staging areas, the staging and opening areas, and so on. The drum inventory data gathered during the remedial investigation should be used to determine the number and size of various operating areas or cells.

At a minimum, the staging, opening, and consolidation areas for wastes other than those that are highly hazardous, should be graded to prevent puddling, lined with polyethylene, and bermed or diked using sandbags or clay. This design will provide only minimal secondary containment, however, and will not be acceptable at many sites. A preferable design at some sites would include a hard surface base or multilayer liner (e.g., three 1-foot layers of graded sands and fines separated by two single layers of 6 mil polyethylene sheeting). Runoff and spills would be contained by an edge berm of the same material. Each cell should be sloped toward a sump to collect spillage and rainfall. The cell, sump, and pump capacity should be adequate to contain runoff from a 10-year, 24-hour storm.

Highly hazardous materials including explosives, radioactive materials, and gas cylinders require separate staging/opening areas that are located as far as possible from the actual drum handling operation.

In addition to the above-mentioned secondary containment measures, these areas should be fenced in and equipped with warning signs.

The decontamination area should always be a hard surface area that will retain wash water by perimeter curbing and collect these liquids by means of a central trough and perimeter sump.

The interim storage area, if required, should be designed to provide a degree of containment consistent with the length of time wastes will be stored onsite. Standards for RCRA permitted storage facilities (40 CFR, Part 264) should be followed where interim storage of three or more months is anticipated.

Figure 4 illustrates the site layout for the drum removal operation at the western trench of the Picillo Farm site in Coventry, Rhode Island.

In addition to these support structures, the contractor is required to make necessary arrangements for power, water supply, and telephone, and to install security fencing and a guard gate to prevent unauthorized access to the contaminated zone.

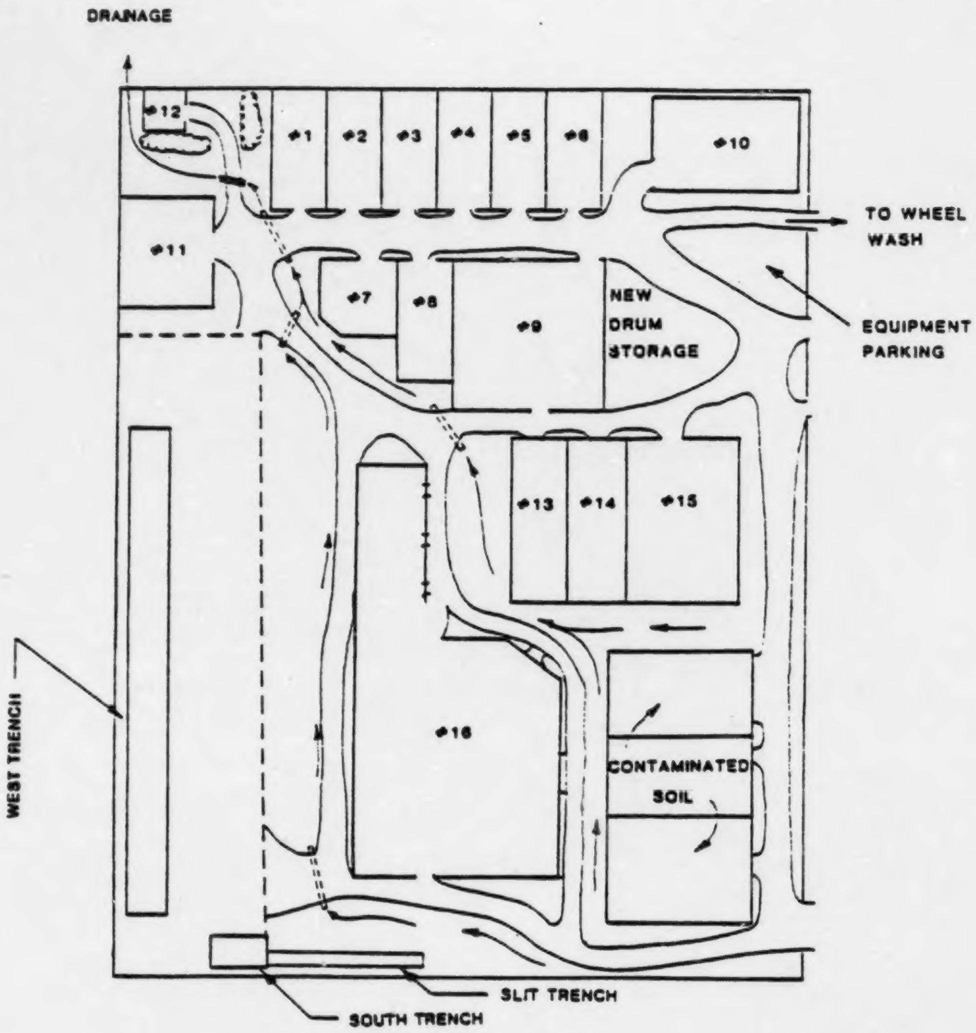
SITE DRAINAGE IMPROVEMENTS

There are a number of provisions that can improve site drainage. In many instances, it is required that the drum consolidation, drum opening, and interim storage areas be graded to prevent standing pools of liquid that can corrode the drum or result in incompatible waste reactions if water reactive wastes are present.

Dikes or berms may be constructed around poorly drained sites to divert the flow of run-on. Drainage ditches can be used to intercept runoff and convey it away from the work areas.

Sites that are poorly drained or swampy may require the construction of special access roads or work areas for heavy excavation equipment. Access may be improved by constructing elevated roadways of stable soils that are wide enough for heavy vehicle use. These areas should be surveyed with metal detectors and/or magnetometers prior to any construction to assure that no drums are being covered.

Timber mats can also be used to provide site access for heavy equipment in swampy, water-logged areas. These mats consist of trees, telephone poles, or railroad ties that are placed parallel to each other, side by side, and bound together with heavy rope or wire. When laid across stretches of swampy areas, they provide a rigid access road or stable working base from which drum excavation activities can be performed.


DRAINAGE
#12
#1
#2
#3
#4
#5
#6
#10
TO WHEEL WASH
#11
#7
#8
#9
NEW DRUM STORAGE
EQUIPMENT PARKING
#13
#14
#15
WEST TRENCH
#16
CONTAMINATED SOIL
SLIT TRENCH
SOUTH TRENCH

CELL	FUNCTION
1-8	SOLIDS STORAGE/MIXING
9	STAGING/SAMPLING
10	DRUM CRUSH, RESERVE STORAGE
11	LAB PACK STORAGE
12	LAB PACK DEMOLITION
13,14	ACID,PCB DRUM STORAGE
15	CONTAMINATED SOIL
16	LIQUID SAMPLE/STAGE/BULK

Figure 4. Picillo Hazardous Waste Site Layout (Western Trench) (Reprinted from Perkins Jordan, Inc., 1982 with permission of the Rhode Island Department of Environmental Management)

SECTION 6

AIR MONITORING AND INSPECTIONS FOR DETERMINING DRUM INTEGRITY

INTRODUCTION

Safe handling of drums that are leaking or prone to rupture is the biggest problem encountered during drum handling operations. The major causes of drum leakage or rupture at hazardous waste sites include:

- Overpressurization, as evidenced by a drum head that is swollen above the chime line and creased from the chime line toward the center of the drum. Under these circumstances, the slightest change in position of the drum can cause the head to blow off (Niggle, 1982).
- Damage caused by abusive handling during transportation and disposal.
- Incomplete tightening of drum bungs.
- Corrosion from contact with soil moisture, acids, or chlorinated hydrocarbons that have been hydrolyzed to hydrochloric acid. Drums may be uniformly pitted or the corrosion can be concentrated in a particular area. Areas that are particularly susceptible to corrosion include the area around the chime and areas where the surface coating has been chipped or the drum surface dented.

A determination of drum integrity usually involves input from several sources of information, which can be divided into two broad categories: information obtained during preliminary assessment and remedial investigation activities, which provide a gross indication of the overall quality of the drums; and information obtained during excavation and removal, which provides detailed information on a drum-by-drum basis. Figure 5 shows potential sources of information on drum integrity during each of these phases. Those activities undertaken as part of site assessment and remedial investigation were discussed in Section 4.

During drum excavation, opening, and recontainerization, investigators must be able to monitor drum integrity on a drum-by-drum basis to determine whether drums can be safely moved or handled. Most companies involved in

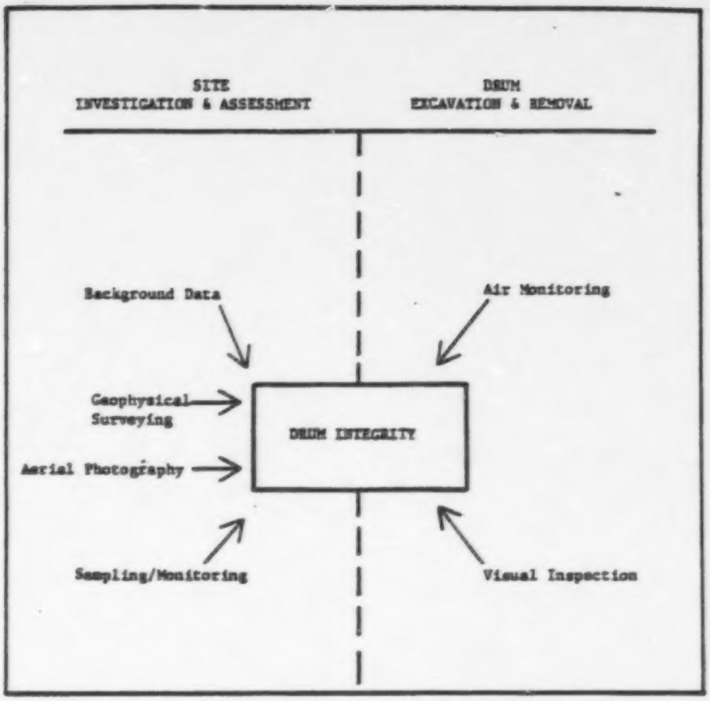

SITE
INVESTIGATION & ASSESSMENT
DRUM
EXCAVATION & REMOVAL
Background Data
Geophysical Surveying
Aerial Photography
Sampling/Monitoring
DRUM INTEGRITY
Air Monitoring
Visual Inspection

Figure 5. Potential Sources of Information on Drum Integrity

site cleanup use a combination of air monitoring and visual inspection of drums to accomplish this. Where the grappler is available, and drums can be handled remotely. Determining drum integrity before handling may not be necessary.

AIR MONITORING

Air monitoring is the most valuable tool for determining drum integrity and worker safety. The requirements for air monitoring vary from site-to-site depending on what is known about drum contents, the availability of funds for monitoring, and the size and location of the site. The monitoring program should, at a minimum, accomplish the following objectives:

- Provide input, along with other information, to establish hot, transition, and clean zones within the waste site (see Section 3) that dictate safety equipment and safety precautions to which site workers must adhere

- Monitor changes in air quality in these zones over time
- Scan for "hot spots" that indicate a sudden release of toxic, flammable, or explosive vapors and radioactivity during such dynamic activities as drum excavation, staging, opening, and consolidation.

Basically, there are two types of monitoring equipment: direct reading instruments, which provide onsite readout of pollutant concentrations, and collection media, used to collect and concentrate pollutants for subsequent laboratory analysis.

Direct Reading Instruments

For sites where the drum contents and their potential hazard are uncertain, the minimum direct reading equipment needed to protect worker safety includes:

- Combustible gas detectors
- Oxygen meters
- Gas/vapor analyzers
- Radiation monitors.

Table 12 summarizes the capabilities and limitations of the most widely used direct reading equipment.

When selecting equipment for field monitoring, a number of factors need to be considered. These include:

- Detection limits
- Accuracy
- Portability and ease of use
- Potential interferences that may impact performance
- Alarm capabilities
- Remote sensing capabilities
- Shelf life/battery storage life
- Calibration equipment and other accessories needed

TABLE 12. SUMMARY OF DIRECT READING AIR MONITORING INSTRUMENTS

Monitoring Need	Instrument	Features	Limitations	Cost	Manufacturers
Combustible Gas	Combustible Gas Detector	• Nonspecific detector for combustible gases measures gas concentration as a percentage of lower explosive limit (LEL) • Lightweight, portable, and easy to use • Visual and audible alarms • Probe provides remote sensing capabilities • 8-12 hr battery operating life for most models • Accuracy varies depending upon the model, accuracies of ± 2 to 3 percent are attainable	• Potential interference from leaded gasoline and silicates, which are more strongly adsorbed on catalyst than oxygen or gas in question. Membranes are available to minimize these effects. • Most models do not measure specific gases • May not function properly in oxygen deficient atmospheres	Approximately $500-700	ENMET Corp. Ann Arbor, MI National Mine Service Co. Pittsburgh, PA Gas Tech Mountain View, CA
Oxygen Deficiency	Oxygen Meter	• Direct readout in percent oxygen • Visual and audible alarm • Lightweight, portable, and easy to use • Probe provides remote sensing capabilities • Accuracies of ± 1 percent are attainable, but depend on the particular model. • Generally 8-10 hr battery life	• High humidity may cause interferences. • Strong oxidants may cause artificially high readout	Approximately $400-700	ENMET Corp. Ann Arbor, MI. National Mine Service Co. Pittsburgh, PA Gas Tech Mountain View, CA

(continued)

TABLE 12. (continued)

Monitoring Need	Instrument	Features	Limitations	Cost	Manufacturers
Combustible Gas/ Oxygen Deficiency	Combination Oxygen Meter and Combustible Gas Detector.	• Measure percent oxygen and gas concentration as a percentage of Lower Explosive Limit (LEL) • Both visual and audible alarm • Remote sensing capabilites • Lightweight, portable, and easy to use • Accuracies of ± 2 percent are attainable but may be as high as ± 10 percent depending on the models.	• Same limitations as oxygen meters and combustible gas detectors	Approximately $700-1,000	ENMET Corp. Ann Arbor, MI National Mine Service Co., Pittsburgh, PA. Gas Tech Mountain View, CA.
Toxic Gas/Vapors	Photoionization Detector (PID) (based on HNU Systems PID)	• Nonspecific gas and vapor detection for both organics and most inorganics • Lightweight (4 kg or 9 lb) and portable • Sensitive to 0.5 ppm benzene. Sensitivity is related to ionization potential of compound • Remote sensing capabilities • Response time of 90 percent in less than 3 seconds • More sensitive to aromatics and unsaturated compounds than the flame ionization dectector (FID) • 10 hr battery operating life • Audible alarm is available	• Does not monitor for specific gases or vapors • Cannot detect hydrogen cyanide or methane • Cannot detect some chlorinated organics	$6,345 including the analyzer ($3,745); portable recorder ($495); calibrated probe assembly ($1,995); audible alarm and instrument corrosion protection are also available for $250	HNU System Inc. Newton, MA.

(continued)

TABLE 12. (continued)

Monitoring Need	Instrument	Features	Limitations	Cost	Manufacturers
Toxic Gas/Vapors (continued)	Flame Ionization Detector (FID) (based on Century Organic Vapor Analyzer, Model 128)	• In the survey mode it functions as a non-specific total hydrocarbon analyzer; in the gas chromatograph (GC) mode, it provides tentative qualitative/quantitative identification • Lightweight (5.4 kg or 12 lb) and portable • Remote sensing probe is available • Response time is 90 percent in 2 sec • 8 hr battery operating life • Sounds audible alarm when predetermined levels are exceeded	• Not suitable for inorganic gases. • Less sensitive to aromatics and unsaturated compounds than PID • Requires skilled technicians to operate the equipment in the GC mode and to analyze the results • Requires changes of columns and gas supply when operated in the GC mode • Since specific chemical standards and calibration columns are needed, the operator must have some idea of the identification of the gas/vapor	Organic Vapor Analyzer $5,050; GC with 2 columns, $880; recorder, $410	Foxboro Analytical S. Norwalk, CT.
	Infrared Analyzer (Based on Miran Model IA)	• Overcomes the limits of most infrared (IR) analyzers by use of a variable filter; can be used to scan through a portion of the spectrum to measure concentrations of several gases or can be set at a particular wavelength to measure a specific gas	• Not as sensitive as the photoionization detector or flame ionization detector • Less portable than other methods of vapor/gas detection • Requires skilled technician to operate and analyze the results when positive chemical identification is needed.	Analyzer, $8,601 Closed loop calibration, $540	Wilkes Infrared Center, Foxboro Analytic, S. Norwalk, CT

(continued)

TABLE 12. (continued)

Monitoring Need	Instrument	Features	Limitations	Cost	Manufacturers
Toxic Gas/Vapors (continued)	Infrared Analyser (con't)	• Detects both organic and inorganic gases • Portable but not as lightweight (14.5 kg or 32 lb) as the photo-ionization or the flame ionization detectors	• Requires power source	• Positive identification requires comparison of spectrum from strip chart recorder with published adsorption spectrum; infrared spectrum is not available for all compounds	
	Detector Tubes	• Provides qualitative, semi-quantitative identification of volatile organics and inorganics • Accuracy of only about ± 25 percent.	• Low accuracy • Subject to leakage during pumping • Requires previous knowledge of gases/vapors in order to select the appropriate detector tube. • Some chemicals interfere with color reaction to give false positive reading	• Multigas detector kit, including hand operated pump, stroke counter, and carrying case, $200 • Detector tubes, about $20 to $24 for package of 10 • Detector tubes are not available for all gases	National Draeger, Inc. Pittsburgh, PA Matheson Gas Products East Rutherford, NJ Bendix/GASTEC Lewisburgh, WV
Radiation	Radiation Meters	• Measures radiation in mR/hr (battery operated) • Probe provides remote sensing capabilities • Accuracy and sensitivity varies considerably with manufacturer and type of meter	• Some meters do not determine type of radiation	• Start at about $500	Solar Electronics Summertown, TN Reactor Experiments Incorporated San Carlos, CA Ludlum Measurements Sweetwater, TN

(continued)

TABLE 12. (continued)

Monitoring Need	Instrument	Features	Limitations	Cost	Manufacturers
Radiation (continued)	Radiation Meters (continued)	• A variety of meters are available. Some measure total ionizing radiation; others are specific for gamma, alpha, or a combination of two or more types			Thermo Election Sante Fe, NM

Sources: Mathamel, 1981; Spittler, 1980; McEnery, 1982; National Mine Service Company, 1980; Gas-Tech, 1980; Enmet, undated; Century System Coporation, 1979; Foxboro Analytical, 1982; HNU Systems, 1982

- Built-in pumping capacity
- Explosion-proofing
- Sampling range.

For monitoring toxic gases/vapors and oxygen deficient atmospheres, the investigator should be attuned to the advantages and limitations of the different equipment types.

Combustible Gas Detectors and Oxygen Meters --

Combustible gas detectors, oxygen meters, and combination combustible gas/oxygen indicators are available from a number of manufacturers. These instruments are easy to operate and reliable. They are available with audio-visual alarms, rechargeable battery packs that provide from 8 to 12 hours of continuous monitoring, and remote sensing capabilities that are facilitated by attaching the sensor leads to a detachable sensor cable (Enmet, undated; Gas Tech, 1980).

The combustible gas detector does not express concentration directly but rather as a percentage of the Lower Explosive Limit (LEL). The LEL is defined as the lowest concentration of flammable gas, by volume of air, that will explode, ignite, or burn when there is an ignition source. Although the combustible gas detector is simple to operate, there are many physical and chemical factors that affect the instrument's response. The instrument will not record accurately in oxygen deficient atmospheres. Leaded gasoline, silicones, and silicates also can impair the response. However, filters are available to minimize these effects (McEntry, 1982; Mathamel, 1981).

The oxygen meter generally measures oxygen concentrations in the range of 0 to 25 percent, and the readout is directly in percent oxygen. High concentrations of strong oxidants such as chlorine will result in erroneously high oxygen readings (McEntry, 1982; Mathamel, 1981).

Gas/Vapor Analyzers--

The most widely used portable instruments for monitoring toxic gases/vapors are the photoionization detector (PID), the flame ionization detector (FID), the infrared analyzer, and the detector tube.

Both the photoionization detector and the flame ionization detector can be adapted with a gas chromatographic (GC) column attachment to provide tentative identification and quantification of hydrocarbons.

The HNU Systems-photoionization detector (HNU-PID) has broad applicability for detecting non-specific gases (HNU System, 1982). It can detect both organic and inorganic gases but will not respond to methane. Lack of response to methane can be an important feature in many site investigations, because it allows the detection of hazardous pollutant concentrations as low as 0.1 ppm without interference from ambient methane concentrations, which can range from 2 to 10 ppm (Driscoll, undated). Since the instrument works on the photoionization principle, sensitivity is related to the wavelength of the exciting lamp and the ionization potential of the vapor to be measured.

The HNU-PID has a sensitivity of about 0.5 ppm benzene and a response time of less than 90 percent in 3 seconds. The Century Organic Vapor Analyzer (OVA) Model 128 is a sensitive, non-specific hydrocarbon flame ionization detector when operated in the total survey mode (see the discussion below on GC mode). There are a number of important similarities and differences between the HNU-PID and the Century OVA 128. Both instruments are lightweight, have a rapid response time, and can be equipped with a rechargeable battery, a probe for remote sensing, and an audible alarm (Foxboro Co., 1982; HNU Systems, 1976). Unlike the HNU-PID, the OVA 128 responds to background methane but does not respond to inorganic gases. It is less sensitive to aromatics and unsaturated hydrocarbons but more sensitve to many chlorinated compounds (Driscoll and Becker, 1979).

The Century OVA 128 can be adapted with a GC column attachment useful for separating mixtures of gaseous compounds to provide tentative compound identification. In the GC mode, the OVA 128 can determine the retention time of an unknown compound. By comparing the retention time with that of known standards, a positive chemical identification can be made. However, since specific chemical standards and calibrated columns are needed, an idea of the nature of the waste components is needed prior to GC analysis. Equipment operation and data interpretation requires use of skilled operators. Photovac, Inc., has developed a portable GC that operates on the photoionization principle (Photovac, Inc., 1980). This instrument is extremely sensitive and is most applicable to situations where volatile components are present in the parts per billion (ppb) range.

The Miran Infrared Analyzer also can be used as a nonspecific gas detector or for specific compound identification. The instrument measures the amount of infrared light absorbed by the gas being analyzed at a selected wavelength using a single beam infrared spectrometer (Foxboro, 1981). Although somewhat simpler to use for positive compound identification, the instrument is less portable and less sensitive than the GC's discussed above. The operator must have some idea of the nature of the vapor, since the wavelength must be preset to determine the absorption spectra of specific compounds. Positive chemical identification requires comparison of printouts from strip recorder charts with published absorption spectra. Absorption spectra are not available for all compounds.

Detector tubes also have the capability of providing qualitative, semiquantitative determinations. The major advantage of this method is that they are very simple to use. However, detector tubes have low accuracy as compared to GC and infrared analysis, response time is slow, and they are subject to leakage. (Gillespie, 1979; Rodgers, 1976). It is not recommended that they be used for onsite monitoring except as a backup to other more sensitive and accurate instruments.

Use of a detector tube requires knowledge of the vapors present in order to select the appropriate detector tube. In some instances other waste components may interfere with the reaction to give a false reading (McEntry, 1982).

Radiation Meters--

There are three types of radiation that can be encountered at hazardous waste sites: alpha, beta, and gamma. Field personnel should be equipped with a portable alpha/beta/gamma survey meter. Gamma radiation monitors that respond with an audible alarm when gamma radiation is encountered should also be worn since there is no convenient method of protecting workers from gamma radiation. In addition, dosimeters that provide an indication of total body exposure to radiation over an extended period of time (time weighted average) should be worn (Gillespie, 1979).

Use of Monitoring Equipment--

All sites must be checked for radioactivity, explosivity, oxygen levels, and toxic gas levels during entry. Once it is established that site entry is safe, air monitoring equipment is then used to establish "zones of concentration," hot, transition, and clean zones, which govern the types of activities that can be conducted in each zone.

When the actual drum handling operation begins, air monitoring equipment should be relied on to monitor any changes that require evacuation or additional safety precautions, especially when conditions require contact with the drums. Specific uses of air monitoring equipment include:

- Scanning the excavation area before and during the use of hand tools or other equipment that require working close to a drum burial area.
- Approaching the drums cautiously once the earth is removed from around the drums and scanning the immediate area before making any physical contact with the drums (lifting, attaching slings or yokes, loading drums onto vehicles for hauling, opening, etc.). Critically swollen drains should be isolated from field personnel until the pressure can be released remotely.
- Relying on direct reading instruments and their audible alarm capabilities to indicate unsafe levels of pollutants or "hot spots" resulting from spills or release of vapors during drum opening, staging, consolidation, and loading.

Collection Media

Where little information is available on drum contents and where funds are available, it may be desirable to obtain positive identification of air pollutants. Since this type of analysis is costly, it is understandably kept to a minimum.

Positive identification is accomplished by chemically absorbing pollutants on collection media with sampling pumps and transporting the samples for subsequent GC/MS or atomic absorption analysis. Mylar bags are also available for collecting air samples but are not recommended unless analysis is immediate. Sampling pumps are commercially available in numerous configurations, but an intrinsically safe National Institute for Occupational Safety and Health (NIOSH) pump is recommended. This type of pump is portable and light enough so that it can be worn by personnel. Table 13 summarizes applications for collection media and the required laboratory analysis.

In using collection media, it is advisable to place pumps in several strategic locations. They could be placed within work areas as well as upwind and downwind of the site. They should also be placed near drums for positive identification of drum contents. If needed, the PID or FID can be used to locate hot spots where pumps should be placed.

VISUAL INSPECTIONS

Visual inspection of drums to determine their integrity before lifting is a widespread practice. Relying on air monitoring equipment to detect any potential problems, the investigator carefully approaches the drum, and the exposed surface is examined for obvious corrosion, swelling, punctures, and bungs. This method, though potentially unsafe, is commonly used where equipment such as front-end loaders and backhoes are being used to lift drums, since under these conditions, worker safety could be jeopardized if the drums rupture or spill. Where drum integrity is questionable and only backhoes or front-end loaders are available, investigators should opt to pump the contents of the drum or place the drum in an overpack rather than lift it on the basis of their visual inspection. The use of the barrel grappler with a plexiglas shield (see Section 7) minimizes the need for visual inspections since worker exposure will not result from rupture.

NONDESTRUCTIVE TESTING METHODS

There are a number of nondestructive testing methods that have the capability of determining cracks, fissures, and the overall integrity of metal surfaces. Ultrasonics and eddy-current techniques, for example, have been used to determine the integrity of storage tanks and vessels and associated piping. However, these methods have not been used to date for determining drum integrity.

There are severe limitations on the usefulness of these methods for determining drum integrity. For the methods to effectively detect cracks or fissures, the drum surface must be fairly clean and chipped paint must be brushed off. This implies that field personnel must be in contact with the drum. The second limitation is that the integrity of the underside of a buried drum cannot be determined.

Since visual inspections are a fairly reliable indication of drum integrity at least at the exposed surface, there seems to be no significant safety advantage to using existing nondestructive methods since the field worker must be in contact with the drum regardless of which method is used.

TABLE 13. SPECIFIC APPLICATIONS FOR AIR SAMPLE COLLECTION MEDIA INCLUDING THE REQUIRED LABORATORY ANALYSIS

Pollutant	Collection Media	Laboratory Analysis
Volatile organics	Carbon tubes Tenax tubes XAD-2 tubes Silica gel tubes	Gas chromatograph/mass spectroscopy (GC/MS)
Particulate organics	Glass fiber filters	GC/MS
Pesticides (including PCBs)	Florisil tubes Polyurethane plugs Glass fiber filters	GC/MS GC/Electron capture
PBBs	Glass fiber filters	GC/MS
Metals	Membrane filters	Atomic absorption (AA)
Volatile inorganics	Impingers/reagent solutions	Wet chemical methods
Particulate inorganics	Membrane filters Glass fiber filters	Wet chemical methods
Cyanides	Filters/impingers	Wet chemical methods

Mathamel, 1981. Table originally printed in the Proceedings of The National Conference on Management of Uncontrolled Hazardous Waste Sites, 1981. Available from Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, MD 20910.

SECTION 7

EXCAVATION, REMOVAL, AND ONSITE HANDLING OF DRUMS

Drum removal is required when it is more cost effective than source control measures or when it is necessary for the protection of public health and the environment. Excavating, removing, and handling drums at hazardous waste sites are generally accomplished with conventional heavy construction equipment. This equipment includes vehicles used for excavating, lifting, loading, hauling, dumping, grading, and compacting onsite soil and waste materials. Equipment commonly used to excavate and transfer waste containers and soils at disposal sites includes the following:

- Crawler tractors (dozers and loaders)
- Rubber-tired loaders
- Backhoes
- Barrel grapplers
- Forklift trucks
- Cranes, draglines, and clamshells
- Scrapers and haulers
- Industrial vacuum loaders
- Hand tools.

In some instances this equipment is modified to improve the safety and efficiency of handling drums. In other instances, specially designed accessories such as slings, drum grabbers, and nylon yokes are used as equipment attachments for drum handling. This section discusses the applications, advantages, and limitations of equipment and accessories for drum handling, emphasizing safety aspects and site-specific conditions that affect equipment selection. This section also discusses specific procedures for excavating drums.

DRUM EXCAVATION AND REMOVAL EQUIPMENT

This subsection describes conventional equipment and methods applicable to hazardous waste drum excavation work. Subsections that follow explain specialized equipment types and accessories used in drum excavation and removal, as well as selection and use of equipment combinations used in drum handling. To illustrate useful equipment combinations, we have included case histories of hazardous waste site drum excavation efforts.

Dozers and Loaders

Dozers and loaders are generally equipped with a hydraulically controlled (versus mechanical cable hoist) blade and bucket lift and can be either crawler-, or rubber-tire-mounted. Crawler machines are equipped with self-laying steel tracks of variable cleat design and width, which provide good ground contact and excellent flotation and traction capabilities. For this reason, crawlers are ideally suited for excavating over rough, unstable surfaces. In marshy or swampy areas where mobility is limited, extra wide tracks are recommended to improve traction.

Dozers and loaders are also available with large rubber-tired wheels that are faster and more mobile than crawler machines on level terrain. Their ability to maneuver on rough, muddy, and sloping terrain, however, depends somewhat on the type of tires. For example, tires with a wide base and low air pressure provide good flotation and traction (Church, 1981).

Crawler dozers equipped with blades of various sizes and shapes (straight to U-shaped) have tremendous earth-moving power and are excellent graders. In drum excavation work these dozers can remove miscellaneous fill or soil overburden, or they can push earth and undamaged or empty drums from unstable surface areas to more accessible areas for lifting and loading operations. The dozers are usually used in combination with other excavation equipment such as backhoes.

Front-end loaders are tractors equipped with buckets for digging, lifting, hauling, and dumping materials. Both crawler-mounted and rubber-tired front-end loaders are widely used in hauling and staging undamaged drums (Figure 6). However, because lifting and loading drums onto front-end loaders usually requires manual assistance, their use should be limited to structurally sound drums.

The crawler loader is an excellent excavator that can carry materials as far as 90 meters (300 feet) (Brunner, 1972). Front-end buckets vary in capacity and design. Medium-sized crawler loaders typically have maximum bucket capacities of 3.8 to 4.5 cubic meters (5-6 cubic yards). Wheel-mounted bucket loaders, for high-production operations on stable surfaces such as paved areas, have bucket capacities to 15 cubic meters (20 cubic yards).

The multiple-purpose bucket, also known as a "bull clam" or "4-in-1," is a hydraulically operated, hinged loader that will clamp onto drums and lift and haul them. When using the bull clam with "choker chains" to bind the drums together, three or four drums can be moved at a time (Brunner, 1972).

One widely used model of rubber-tired front-end loaders is the "Bobcat" series manufactured by Clark Equipment Company (Figure 7). This machine is well suited for drum loading and transporting on stable working surfaces and

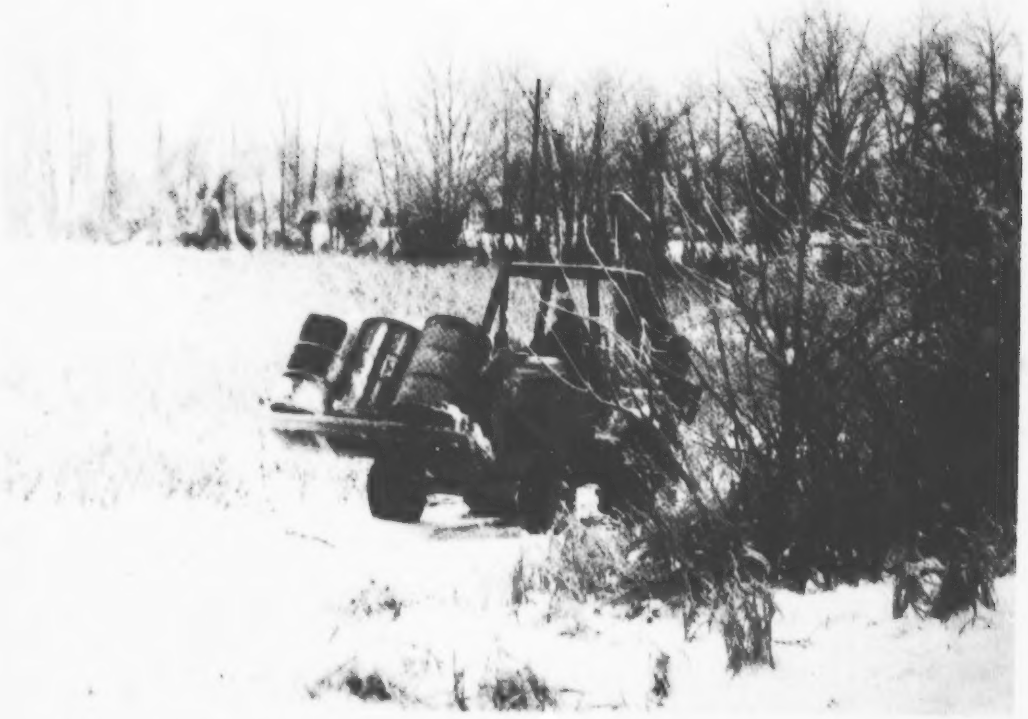
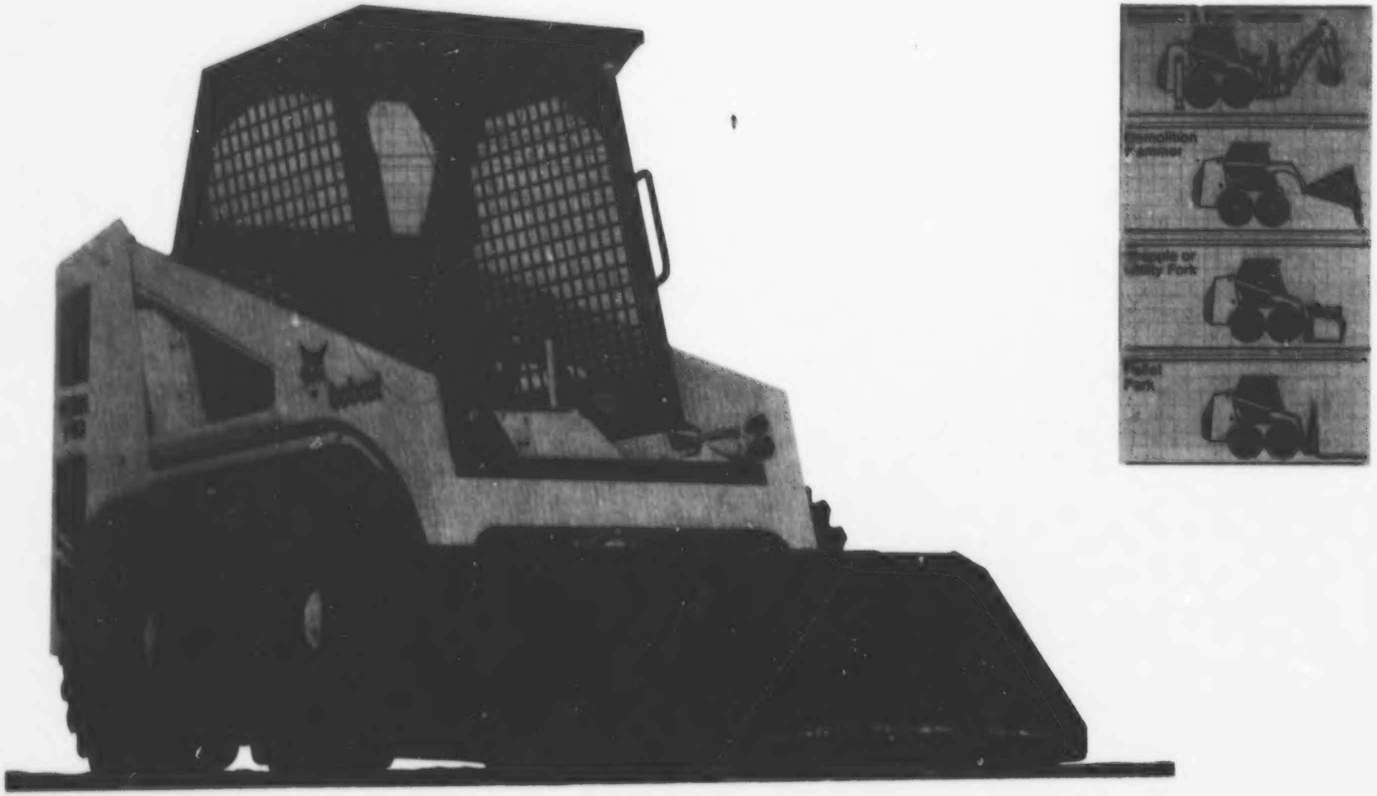


Figure 6. Front-End Loader Hauling Drums at Waste Site

Source: U.S. EPA, 1980a


Bobcat
Demolition Hammer
Grapple or Utility Fork
Pallet Fork

1. Loader 742 DS has DS rating by NFPA for fire hazards.
2. Special Applications Kit has operator protection at cab openings.

Figure 7. Bobcat Rubber-Tired Loader and Attachments

(Courtesy of Clark Equipment Co. Fargo, ND) can be equipped with a variety of hydraulically controlled bucket, grapple, and lifting attachments. The bobcat can also be converted to an agile, small-capacity backhoe excavator.

Backhoes

Backhoes (Figure 8), also known as pull shovels or power hoes, are generally crawler-mounted, hydraulically operated vehicles with various sized steel-toothed buckets ("dippers") attached to boom and dipper-arm assemblies of varying lengths. Backhoes are used for trenching and subsurface excavation. They can dig as deep as 11 to 12 meters (35-40 feet), carry from 0.2 to 2.7 cubic meters (0.25-3.5 cubic yards) of material, and reach up to 18 meters (60 feet).

Backhoes are the most versatile and widely used vehicles for drum handling. They are suitable for removing the soil covering the drums and for excavating and lifting the drums. Their long boom assemblies permit removal of drums from considerable depths and allow the equipment operator to work away from immediate and potentially unsafe disposal areas. When drums are buried deeper than the maximum reach of the backhoe's boom and dipper assembly, a "working bench" can be excavated for the backhoe next to the trench so that the vehicle can excavate to the required depth. There are also several modifications to the conventional backhoe that can further increase its versatility.

Smaller backhoes with rubber tires are useful for fast excavation on stable working surfaces. One frequently used smaller backhoe is a wheel-mounted combination backhoe and front-end loader (Figure 9). This vehicle can excavate, lift, load, haul, and dump soil and waste materials (including both crushed and undamaged drums). Its operation, however, is generally restricted to relatively flat and stable working surfaces.

The conventional backhoe dipper shovel can be replaced by several types of special purpose, hydraulically controlled accessory attachments, including:

- Drum grapple
- Clamshell buckets
- Loader buckets
- Air percussion hammers
- Rotating drum grapples
- Drum plungers for sample collection (see Section 8).

Perhaps the most useful backhoe attachment for drum excavation work is the drum grapple. This articulated backhoe attachment incorporates wrist action motion and can rotate 360 degrees along the plane of its attachment assembly platform. The grapple also hydraulically self adjusts its grip

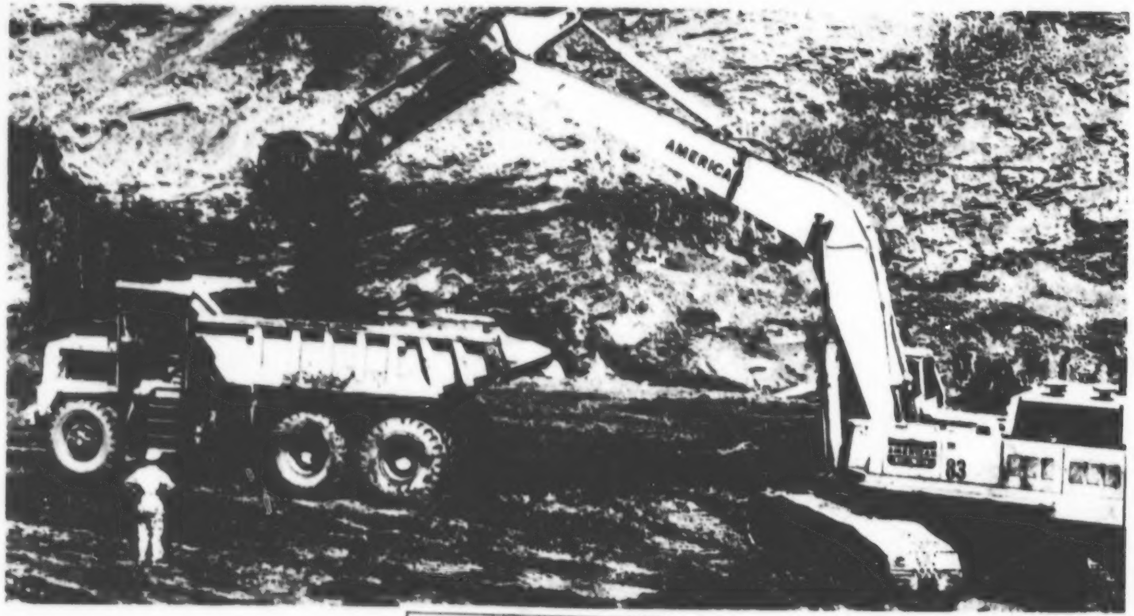


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Figure 8. American Backhoe Loading Excavated Soil Onto Truck

(Courtesy of Amhoist, St. Paul, MN)

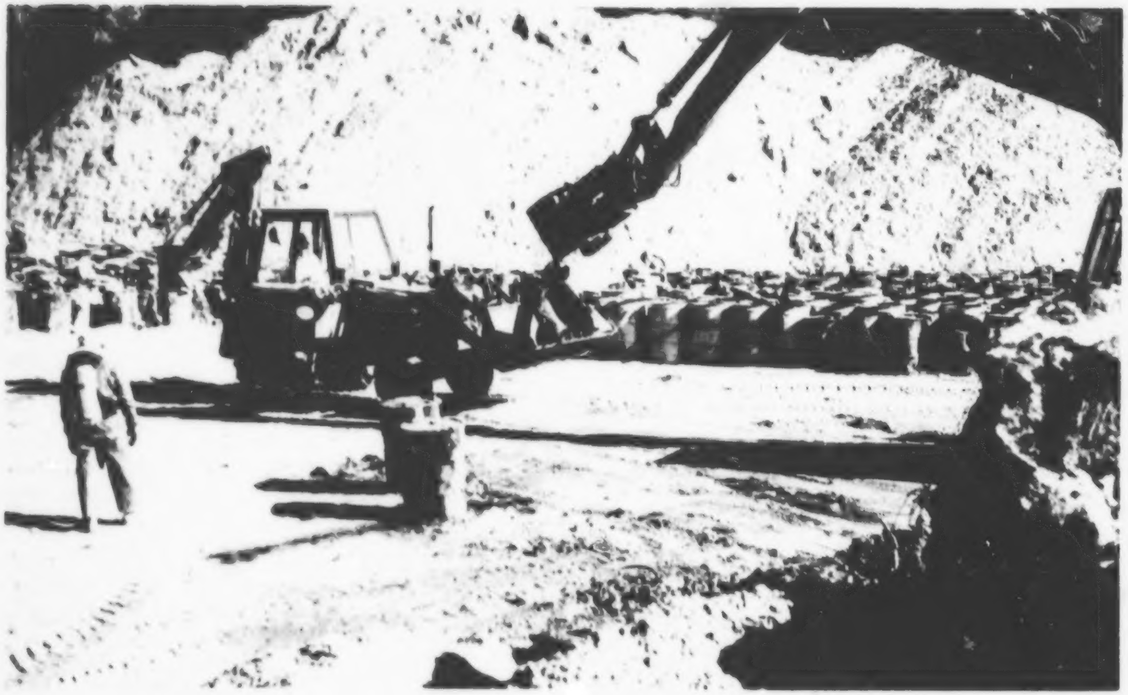


Figure 9. Modified Backhoe (Barrel Grappler) Loading Drums Onto Combination Backhoe and Front-End Loader

(Courtesy of O.H. Materials, Findlay, OH) radius so that it can grab and lift containers of various size and lower them gradually without spillage (verbal communication with J. Walker and R. Panning, O.H. Materials Co., Findlay, Ohio). When the drum grapple assembly is attached to a backhoe dipper arm, the conventional backhoe becomes what is known as a "grappler" (Figure 10).

Grapplers

Grapplers, as discussed above, are specially modified crawler-mounted hydraulic backhoes with rotating drum grapple heads replacing the conventional dipper bucket. One design by O.H. Materials for hazardous waste work, has a grapple and dipper-arm assembly with a reach in excess of 9 meters (30 feet) and is used with a Caterpillar 215 or 225 backhoe. The R.J. Corman Co., and United Hydraulics of Eugene, Oregon, have also designed grapplers with similar capabilities.

When controlled by experienced backhoe operators, the grappler can safely and efficiently grab, lift, and relocate or dump hazardous waste drums; and selectively remove partially buried or totally uncovered drums, one at a time from trench excavations, waste disposal pits, and other drum disposal areas of varying slope and roughness (Figure 11). It is particularly useful in selectively removing drums from stacks piled several drums high and from the upper floors of drum storage or disposal warehouses; and can be used for relocating and segregating undamaged waste drums, overpacking damaged drums, and as a "scrap grabber" for rapidly lifting, moving, and dumping a number of damaged drums at the same time.

Forklift Trucks

Heavy-duty, rubber-tired forklift trucks are widely used in drum handling operations. The advantage of the forklift truck is that it is compact, maneuverable, and very versatile. Its use in drum handling depends largely on the type of forklift attachment with which it is adapted. The various attachments are discussed in the subsection "Accessories for Drum Excavation Equipment." When adapted with drum grabbers, the forklift efficiently stages, segregates, and loads structurally sound drums that are upright. When used with drum lifting hooks and slings, the forklift can lift drums from shallow disposal areas. This operation, however, requires manual assistance from field personnel and, therefore, should be used when drums are structurally sound.

Cranes, Clamshells, and Draglines

Large cable-operated cranes are sometimes fitted with clamshell buckets, (Figure 12) drum grapples, magnets, hoists, slings, and lifters for large-scale drum excavation, lifting, and staging at sites with unrestricted working space. They can also be adapted for use as dragline excavators (Figure 13) for deeper excavations over large areas.

Clamshells and dragline excavators with bucket capacities up to 4.6 cubic meters (6 cubic yards) and booms as long as 30 meters (100 feet) can excavate heavy loads from depths of 15 to 18 meters (50-60 feet).

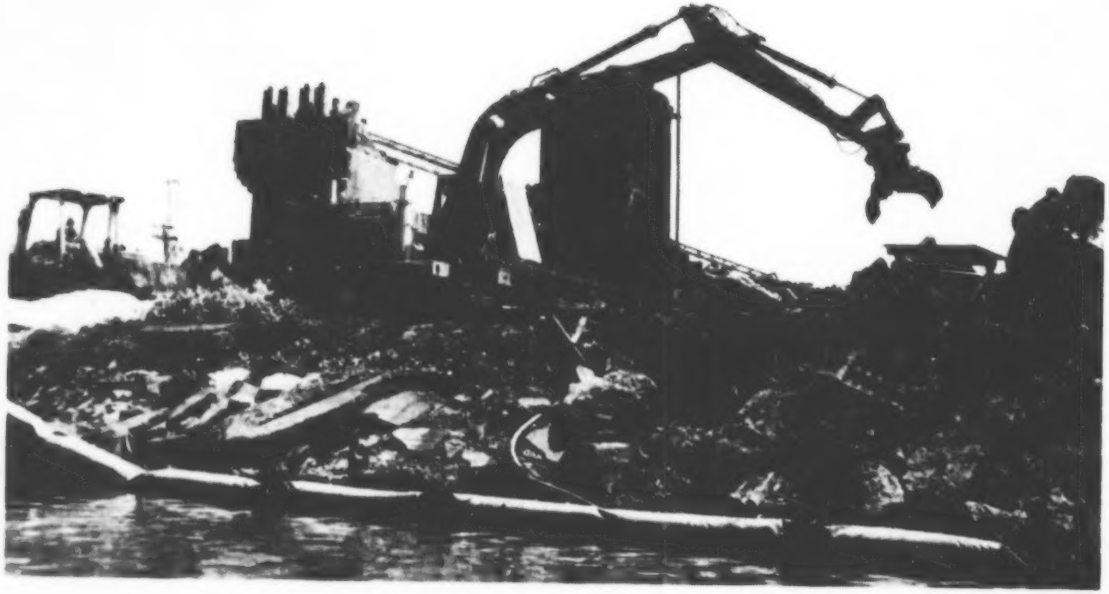


Figure 10. The Barrel Grappler

(Courtesy of O.H. Materials Co., Findlay, OH)

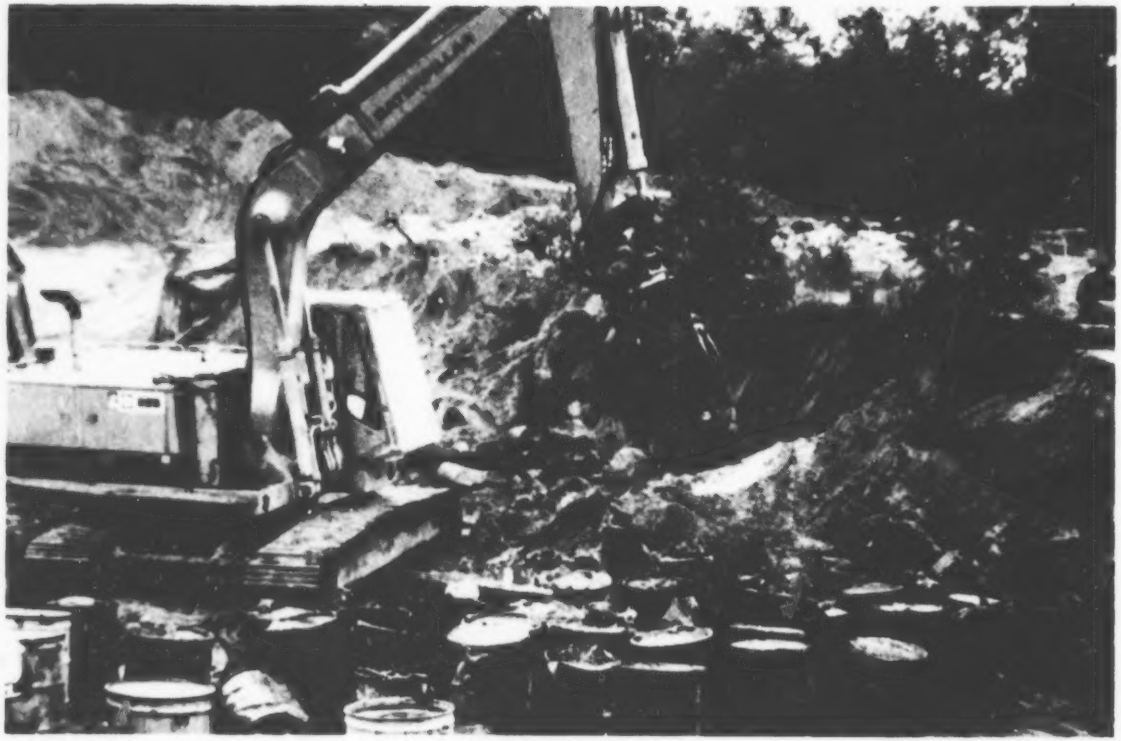


Figure 11. Barrel Grappler Removing Drums from Pit Excavation

(Courtesy of O.H. Materials Co., Findlay, OH)

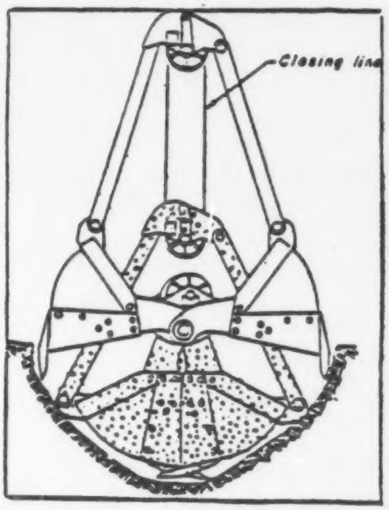


Figure 12. Clamshell Bucket for Crane Attachment
(Source: U.S. EPA, 1982b)

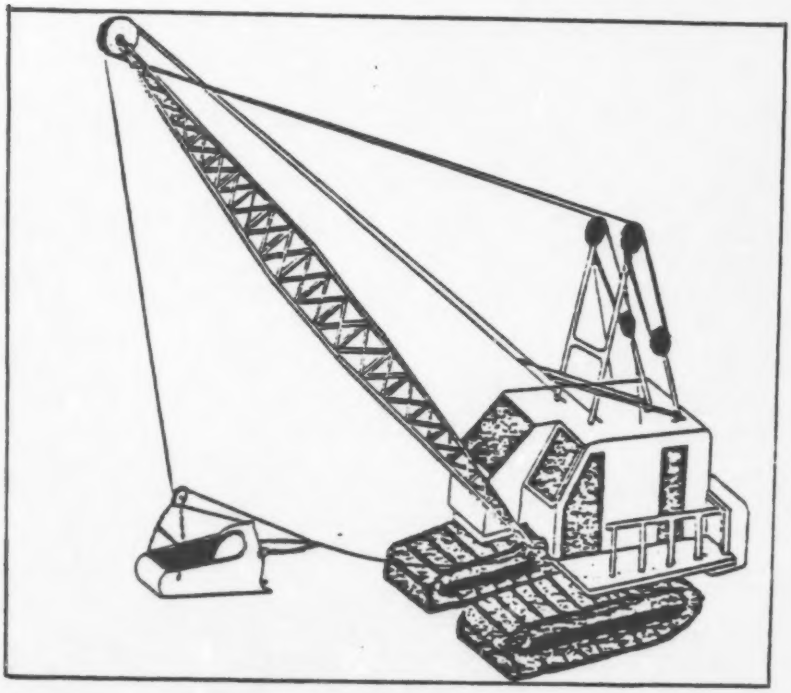


Figure 13. A Dragline
(Source: U.S. EPA, 1982b)

Because of their long reach and deep excavation capabilities, clamshells, draglines, and other crane-based operations are indispensable in some drum handling operations. They are economical for large-scale drum removal where drums are buried deeper than 9 to 12 meters (30-40 feet). Wheel-mounted cranes equipped with long booms can lift drums from warehouses or congested urban areas that are inaccessible to other types of equipment.

Cranes are either crawler-mounted for better stability over rough, muddy terrain or wheel-mounted for mobility on more stable surfaces. Cranes also can be mounted on barges for drum removal from congested, urban disposal areas accessible only from adjacent rivers or bays. Smaller, rubber-tired, truck-mounted hydraulic cranes ("cherry pickers") are useful in drum lifting and staging in confined working areas with stable surfaces.

Although clamshells and draglines have excellent lifting power, they are limited in mobility and rotation speed, which slows drum lifting and staging operations. Smaller, hydraulic backhoes equipped with wrist action dippers or grapples are more mobile, dexterous, and generally better adapted than cranes and draglines for combined drum excavation and relocation operations.

Scrapers and Haulers

The use of wheel-mounted scrapers in drum excavation work are generally used to remove and haul surface cover material at large disposal sites where drums are known to be buried at given depths or in given areas (discrete trenches or pits). They are also useful in respreading and compacting cover soils after drum removal.

Scrapers are available as both self-propelled, self-loading vehicles, and as models that are push-loaded by crawler tractors. Soft- to medium-density cover soils and fill favor the self-loading scraper; medium to hard rock and earth favor the use of the push-loaded machine. The hauling capacities of scrapers range from 1.5 to 30 cubic meters (2 to 40 cubic yards). These earthmoving machines can haul cover material economically over relatively long distances--more than 300 meters (1,000 feet) for self-propelled scrapers (Church, 1981).

A variety of haul trucks are available for transporting excavated materials and waste drums, both off-the-road and on-the-road. Haulers are large rubber-tired vehicles available as single-trailer, 2-, or 3-axle vehicles and as double-trailer, multiple-axle haulers. Their rated haul capacities range from 0.9 to 91 metric tons (1-100 tons), and they are available as bottom-dump, rear-dump, and side-dump vehicles. Small 1- and 2-MT (1-2 ton) haul trucks are used most commonly in drum transport operations. Simple flatbed or enclosed trailer trucks of varying lengths are also used in offsite transport of excavated drums.

At hazardous waste disposal sites, haul trucks are most useful for hauling excavated drums (damaged or undamaged) to offsite secure landfills or selected drum reburial sites. Drums can be carefully loaded onto and removed from haulers using backhoes, cranes, loaders, and forklift trucks, usually with manual assistance from field workers. Barrel grapplers, however, can usually perform this task without manual assistance.

Industrial Vacuum Loaders

Industrial vacuum loaders (Figure 14) such as the "Supersucker" (Super Products, undated) and the "Vactor" (Peabody Myers, undated) can be used in large-scale drum removal operations to remove remaining soil or pools of liquid waste from around the drums during excavation. Using industrial loaders for soil removal is safer and more efficient than using hand tools. The Supersucker and the Vactor are vehicle-mounted, high-strength vacuums that can carry solids, liquids, metal, and plastic scraps and almost any other material that can fit through a 20 cm (8 in) hose. They are equipped with a boom and up to 150 meters (500 feet) of hose that allow them to convey materials from otherwise inaccessible areas. Their mobility and large capacity eliminate the need to transfer materials to other vehicles before hauling for disposal or treatment. Vacuum loaders can operate in either a solids or liquids handling mode. Changing modes can be done quickly with an exterior adjustment and without emptying the load (Figure 15). This allows the Vactor or Supersucker to convey both soils and pools of liquid waste without dumping the load.

Hand Tools

Direct handling of drums by field workers is often necessary during drum excavation, lifting, and unloading operations. However, these operations should be minimized to limit worker exposure to waste-related hazards, and the workers should be outfitted at all times with appropriate protective clothing and safety devices.

There are a number of conventional and specialized tools available for direct handling of waste containers. Activities that may require such handling include the following:

- Removing soil and debris from around the surface of drums before excavation
- Excavating and removing drums from critical areas (next to buried gas lines, adjacent drums with noncompatible wastes, building foundations, etc.)
- Placing chains, grippers/lifters, hoists/hooks, and slings around drums for lifting and transporting by front-end loaders, cranes, forklifts, etc.
- Excavating and segregating small numbers of drums (<10) in scattered locations
- Staging and segregating drums in storage areas

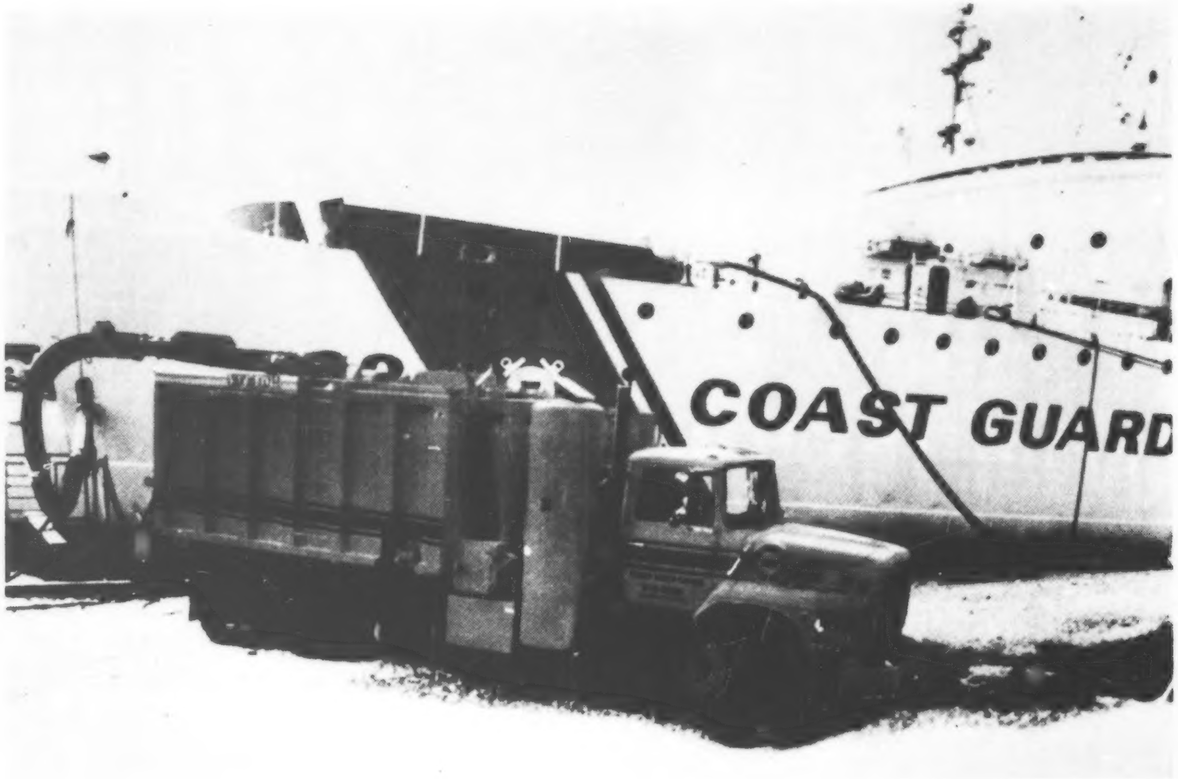

COAST GUARD

Figure 14. Peabody-Myers High-Strength Industrial Vactor

(Courtesy of Peabody-Myers, Streator, IL)

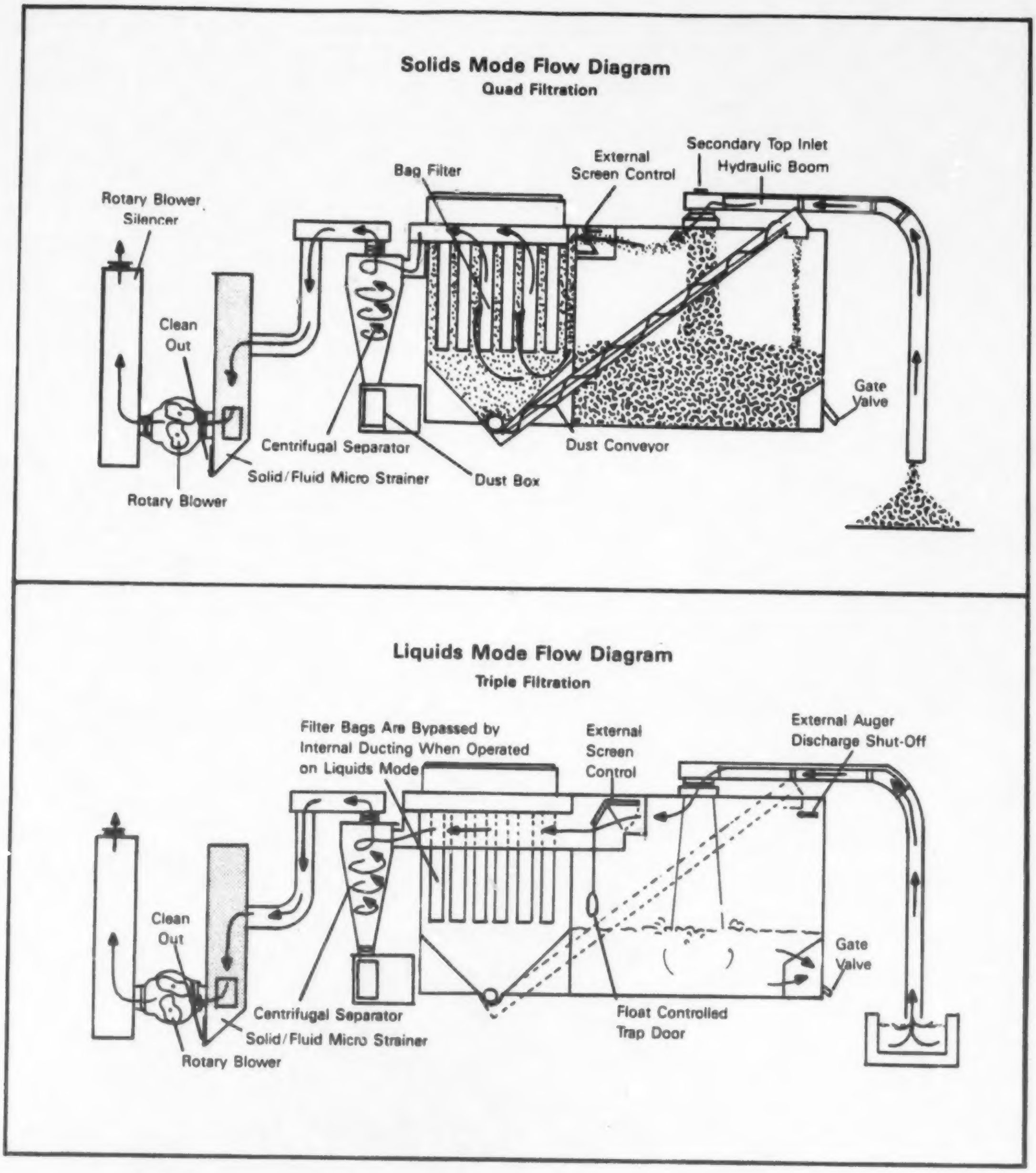

Solids Mode Flow Diagram
Quad Filtration
Bag Filter
External Screen Control
Secondary Top Inlet
Hydraulic Boom
Rotary Blower Silencer
Clean Out
Gate Valve
Centrifugal Separator
Dust Conveyor
Solid/Fluid Micro Strainer
Dust Box
Rotary Blower
Liquids Mode Flow Diagram
Triple Filtration
Filter Bags Are Bypassed by Internal Ducting When Operated on Liquids Mode
External Screen Control
External Auger Discharge Shut-Off
Clean Out
Gate Valve
Centrifugal Separator
Float Controlled Trap Door
Solid/Fluid Micro Strainer
Rotary Blower

Figure 15. Liquids and Solids Handling by an Industrial Vacuum Loader
(Courtesy of Peabody-Myers, Streator, IL)

- Opening drums for sample collection and compatibility testing (see Section 8).

It should be noted that mechanical equipment can successfully replace hand operations in most of these instances, depending on safety and cost tradeoffs.

Hand tools useful in excavating and removing drums include shovels and picks made of special non-sparking manganese-bronze, molybdenum, or aluminum alloys. Hand-operated pneumatic jackhammers are useful for excavating through pavement, rock, or brick to get to buried drums. Drum trucks (special hand trucks) and drum dollies can be used for transporting excavated drums over short distances. Additional equipment and accessories used for drum lifting and handling are discussed in the following section.

ACCESSORIES FOR DRUM EXCAVATION EQUIPMENT

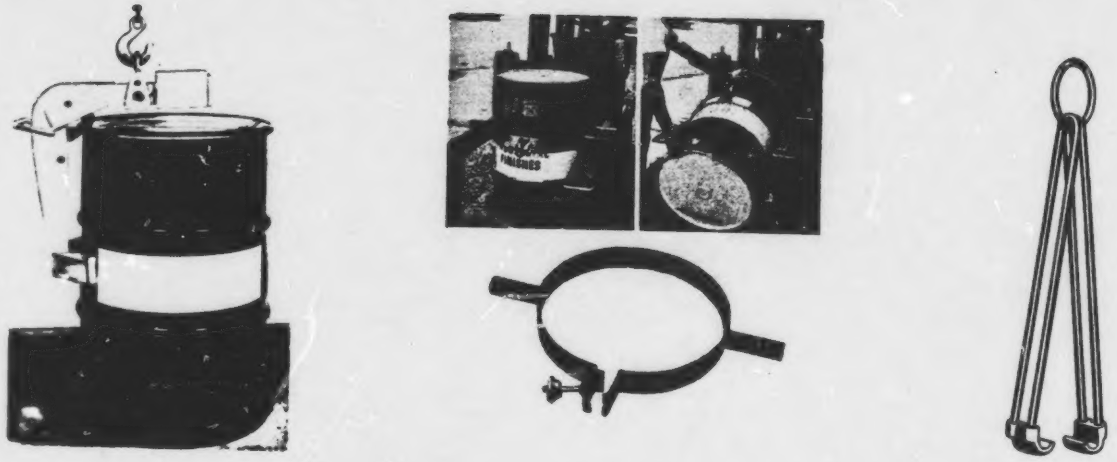
There are a number of commercially available equipment accessories that can be used in drum handling (excavation, lifting, and transport) at hazardous waste sites. These accessories are generally designed for conventional use as attachments to forklift trucks or in manual container handling operations. However, they may be adapted for use with other drum excavation equipment discussed in the previous section. Other accessories include health and safety equipment available for routine use during drum excavation work where drum explosions or ruptures may pose a threat to field workers and equipment operators.

Drum Lifting and Transfer Accessories

There are several types of drum excavation and lifting accessories for backhoes and cranes (e.g., magnets, loader buckets, clamshell and dragline buckets, and drum grapples). These accessories have been discussed in the previous subsection. Other accessories include drum slings and hoist attachments, drum grippers, and drum lifters and dumpers.

Drum lifting attachments and slings include heavy-duty nylon yokes and straps and a variety of steel or metal alloy mechanical hoist attachments (Figure 16) of variable capacity (up to 1800 kg or 4000 lb). The attachments are adjustable for different drum heights and diameters, and some models can lift at any angle (BASCO, 1982). They can be used on backhoes, cranes, and forklift trucks.

Drum lifting attachments are most useful to lift and relocate drums to staging areas in congested, hard to access areas of waste sites. Drums lifted with most of these attachments must be structurally sound and should not contain explosive or shock-sensitive wastes. Wide nylon or canvas yokes are the best suited attachments for handling drums of questionable integrity since they can be wrapped around the drum so as to exert little pressure or stress on any particular part of the drum. The major disadvantage of using these lifting attachments is that workers must be near the drums to properly

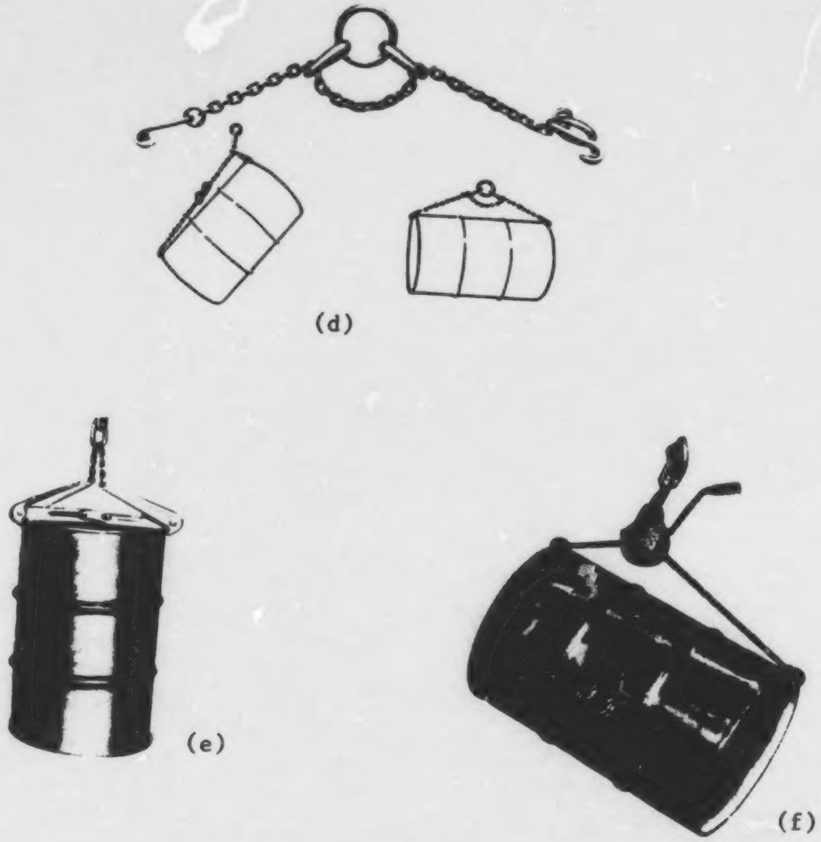


(a) (b) (c)

(a) Lifting hook for handling any type of drum.
(b) Drum band for handling and emptying 55 gallon drums with forklift.
(c) Drum lifting hook for steel drums (may be used with barrels).

Figure 16. Mechanical Drum Lifting Attachments

(Courtesy of BASCO, Chicago, IL)



(d) Adjustable slings for handling barrels horizontally; vertical slings are also available.
(e) Drum chime tongs to handle drums in upright position with or without heads.
(f) Crank operated drum lifter.

Figure 16. (continued)

(Courtesy of BASCO, Chicago, IL)

position and secure the slings, chains, yokes, etc. These operations tend to be time consuming as well as dangerous if the drum contents are unknown or hazardous. Drums could easily be damaged during these operations and leaks could occur. For lifting drums that may contain flammable wastes, lifting attachments must be made of nonsparking materials such as nylon, canvas, rope, or bronze.

Drum grippers (Figure 17), also known as drum totes or grabbers, are forklift attachments that can also be adapted to crawler-mounted backhoes and loaders for lifting and transporting drums. Adjustable drum totes can handle two similar or different sized drums simultaneously (30- and 55-gallons), with a maximum capacity of 680 kilograms per drum (1,500 lb) (BASCO, 1982). Drum totes are most useful as forklift attachments for relocating and segregating drums that have been stacked upright at waste disposal sites. A single drum grabber on a backhoe boom or loader can selectively remove drums from exposed waste trenches or pits provided the drums are in an upright position.

Drum lifters and dumpers are available as hydraulically or mechanically operated forklift attachments, as manually operated hoist or crane attachments (Figures 18 and 19), and as portable low- and high-level hydraulic dumpers (Figure 20). These equipment types are useful for stacking structurally sound drums in temporary storage areas, elevating drums to loading platforms or flatbed trucks, and dumping the contents of drums into "compatibility chambers" (Section 9).

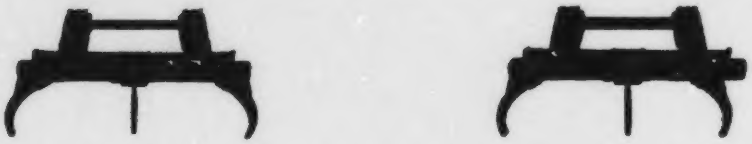
The drum grabbers, grippers, and lifters described above may not be cost effective for a large site in which many drums must be transported efficiently from the excavation area to a staging area. Grouping drums onto a compartmentalized "scale pan" for removal by flat bed truck with loading and unloading capability may be more suitable where site conditions permit truck traffic. Another alternative would be to construct a "drum sled" similar to the conceptual design shown in Figure 21 (Perkins Jordan Inc., 1982). The sled, which can be attached to a dozer, can haul drums over level or gently sloping terrain.

Worker Safety and Drum Protection Accessories

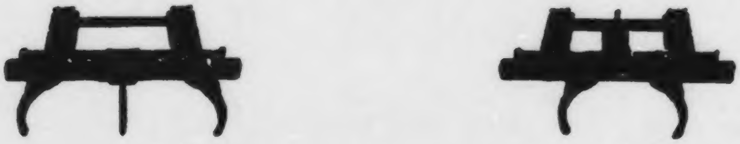
Equipment accessories used for operator safety and drum protection include plexiglas safety shields for vehicle cabs (Figure 22) and steel bars, or "morman bars."

Plexiglas safety shields are installed to provide an explosion- and splatter-proof layer around the cabs of backhoes, loaders, and cranes when excavating drums of explosive or liquid hazardous wastes. They should also be used on forklift trucks, in which the operator is near to the drums being handled.

Morman bars are cast-iron bars that are placed over the teeth of various excavator buckets (backhoe dippers, loader buckets, dozer blades, clamshells) to blunt the digging edge of the buckets to avoid drum punctures and spills.



Adjusted for two 55-gallon drums, ...for one 55- and one 30-gallon drums,



...for two 30-gallon drums, ...for one 55-gallon drum...

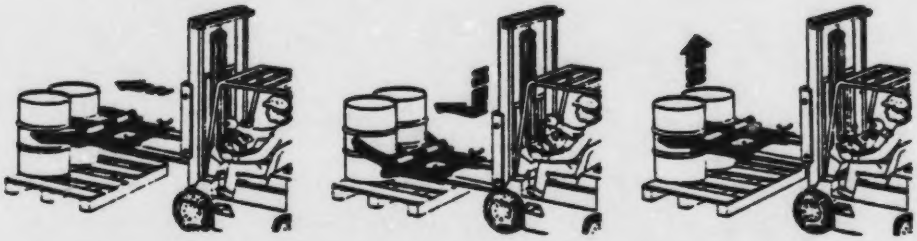


Figure 17. Drum Gripper Attachment for Forklifts
(Courtesy of BASCO, Chicago, IL)

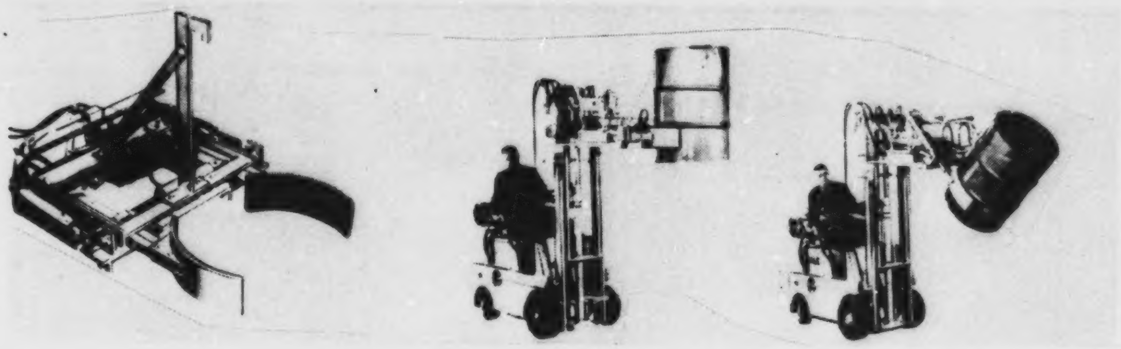


Figure 18. Hydraulic Drum Grab

(Courtesy of BASCO, Chicago, IL)

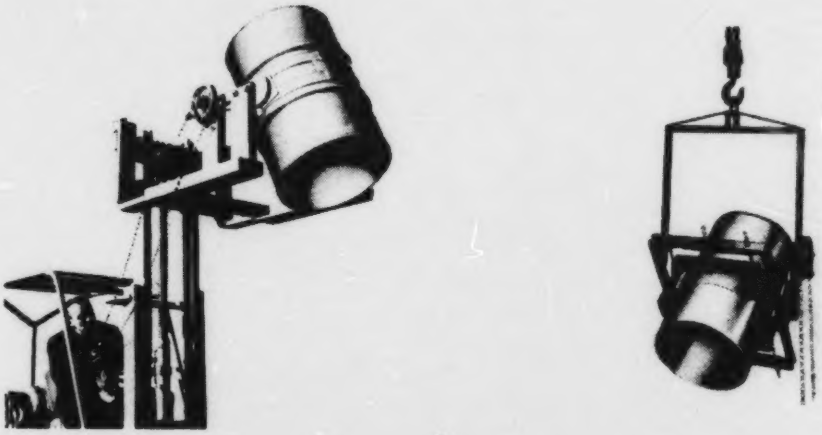


Figure 19. Forklift-Mounted Drum Dumper and Hoister-Crane-Mounted Drum Dumper

(Courtesy of BASCO, Chicago, IL)

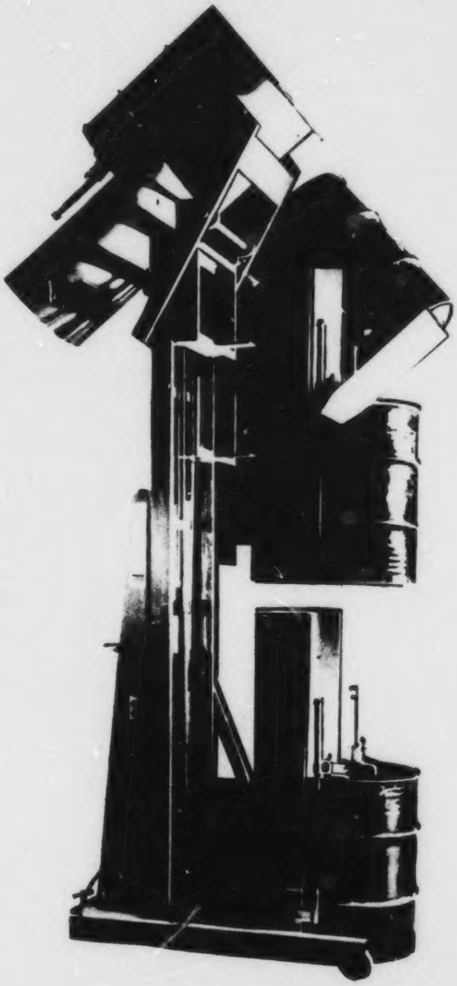
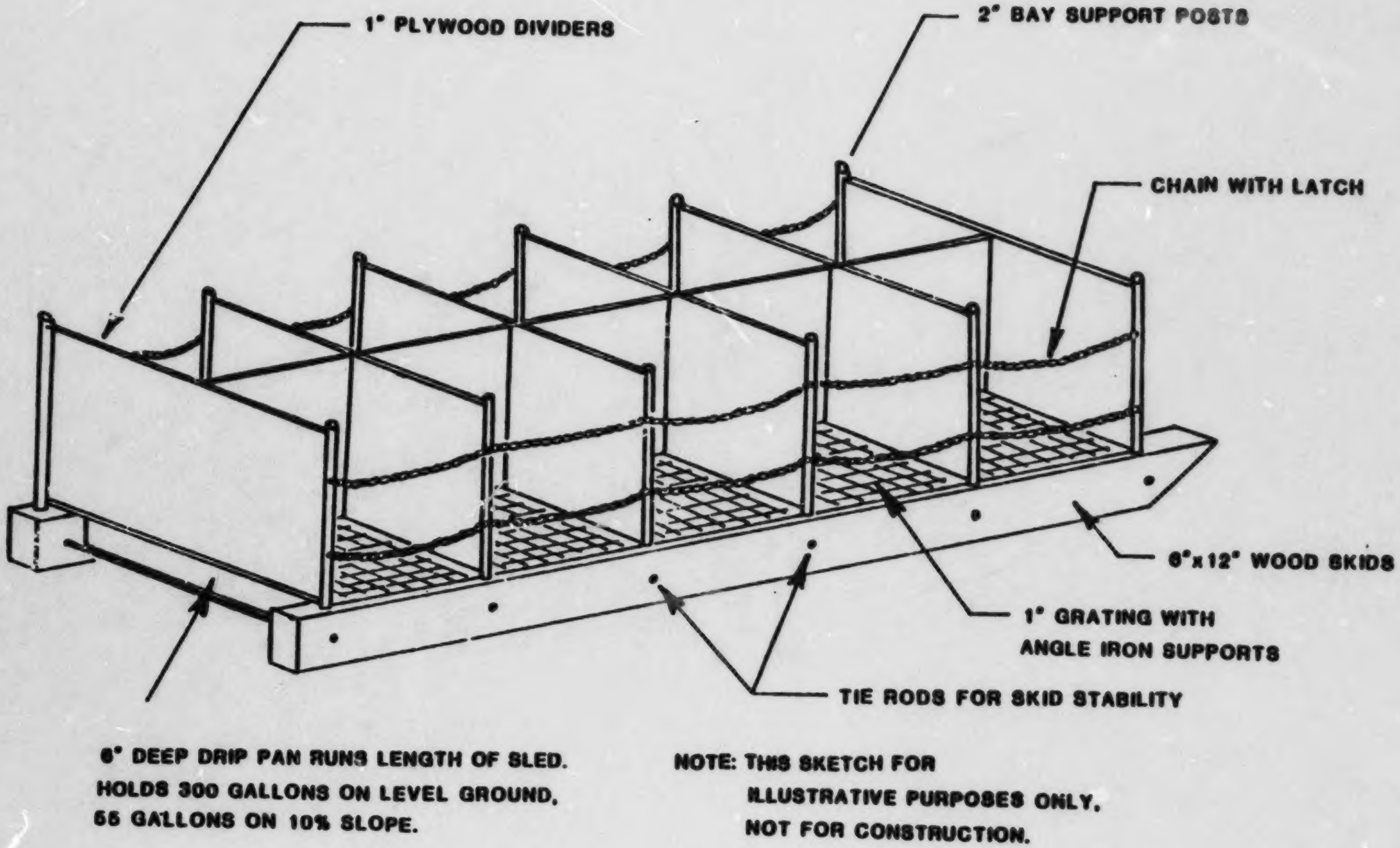


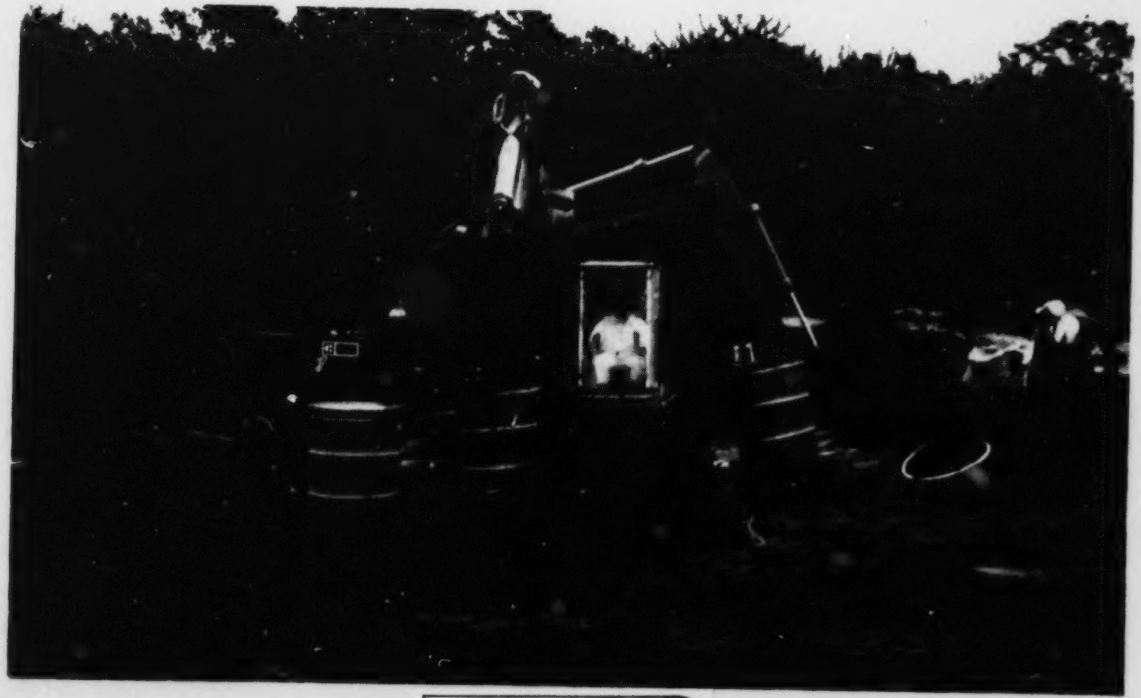
Figure 20. Portable Hydraulic Drum Dumper

(Courtesy of BASCO, Chicago, IL)


1" PLYWOOD DIVIDERS
2" BAY SUPPORT POSTS
CHAIN WITH LATCH
6"x12" WOOD SKIDS
1" GRATING WITH ANGLE IRON SUPPORTS
TIE RODS FOR SKID STABILITY
6" DEEP DRIP PAN RUNS LENGTH OF SLED. HOLDS 300 GALLONS ON LEVEL GROUND, 55 GALLONS ON 10% SLOPE.

NOTE: THIS SKETCH FOR ILLUSTRATIVE PURPOSES ONLY. NOT FOR CONSTRUCTION.

Figure 21. Drum Sled
Note: The sled has not been used in actual field conditions
(Reprinted from Perkins Jordan, Inc., 1982 with permission of the Rhode Island Department of Environmental Management)



Reproduced from
best available copy.

Figure 22. Plexiglas Safety Shield on Cap of Grappler During Overpacking Operation (Note second backhoe in background)

(Courtesy of O.H. Materials Co., Findlay, OH)

Such bars can also be custom made of nonsparking metal alloys for excavating potentially explosive drums. Excavating buckets fitted with nonsparking teeth provide additional protection when working with potentially explosive drums.

Safety accessories that should be carried in the cabs of all vehicles involved in drum handling include fire extinguishers, spare respirators and respirator cartridges, and self-contained breathing apparatus (SCBA) with air tanks and harnesses. Field workers should wear appropriate protective clothing at all times.

SELECTION AND USE OF DRUM EXCAVATION AND REMOVAL EQUIPMENT

Drum excavation and removal equipment is used to perform several distinct, important functions including the following:

- Excavating to the depth of buried drums and removing surface cover over buried drums
- Excavating around buried drums to free them for removal
- Removing (lifting) drums from exposed pits and trenches
- Loading and transporting drums to onsite storage areas
- Sampling, segregating, bulking, storing, and recontainerizing (e.g., overpacking) drums
- Transporting offsite for appropriate storage, treatment, or disposal.

The choice of equipment for drum handling is based on inherent capabilities and limitations of the equipment, site-specific conditions that affect equipment performance, the necessity to protect worker safety, and costs. Table 14 summarizes the capabilities and limitations of the drum excavation and removal equipment considered for this manual. Generally, a combination of equipment and accessories is required for a particular drum handling problem. Table 15 summarizes the effect that site-specific factors and safety have on equipment selection and use.

The most significant ways to improve the safety of a drum handling operation are to keep the operation as remote from workers as possible, to avoid sudden releases of chemicals if the operation cannot be remote, and to provide adequate safety gear and equipment to protect the worker if spillage or contact with the drums is unavoidable. Implementing these precautionary measures should be an overriding factor in selecting equipment for excavating and manipulating drums.

TABLE 14. DRUM EXCAVATION/REMOVAL EQUIPMENT CAPABILITIES AND LIMITATIONS

	Main Functions and Capabilities							
Equipment Type	Gross Excavation of Cover Materials	Gross Excavations to Depths	Precise Excavations Around Drums	Drum Lifting & Transfer	Drum Loading & Onsite Transport	Drum Segregation & Recontainerization	Long Distance Hauling/ Offsite Transport	Major Limitations and Disadvantages
Crawler dozers (and attachments)	X	X	X	X	X			Limited speed and mobility
Crawler loaders (and attachments)	X		X		X	X		Generally requires loading of drums by hand; short-distance transport only
Rubber-tired loaders (and attachments)	X		X		X	X		Restricted to fairly stable surfaces; generally requires loading of drums by hand
Backhoes (and attachments)	X	X	X	X	X			Very versatile but cannot manipulate drums without worker intervention
Grapplers (modified backhoes)				X	X	X		Most versatile type of equipment but limited to handling one drum at a time
Cranes and attachments (magnets, clamshells, draglines, etc.)	X	X		X		X		Very limited mobility; slow
Scrapers	X				X		X	Imprecise loading action; requires manual assistance for drum loading
Box Trailers					X		X	Used only to transport drums offsite
Hand Tools/Hand Manipulation			X	X	X	X		Requires close worker contact with wastes

(continued)

TABLE 14. (continued)

	Main Functions and Capabilities							
Equipment Type	Gross Excavation of Cover Materials	Gross Excavations to Depths	Precise Excavations Around Drums	Drum Lifting & Transfer	Drum Loading & Onsite Transport	Drum Segregation & Recontainer-ization	Long Distance Hauling/ Offsite Transport	Major Limitations and Disadvantages
Forklift Trucks (and attachments)				X	X	X		Limited to stable working surfaces and to lifting drums in an upright position
Drum Lifters and Dumpers				X	X	X		Close worker contact with wastes; one drum at a time; drums must be upright for grabbing
Industrial Vacuum Loaders	X		X					Costly to contract equipment; cost effective only for large scale operations

TABLE 15. EFFECT OF SITE-SPECIFIC VARIABLES ON SELECTION AND USE OF DRUM EXCAVATION AND HANDLING EQUIPMENT

Site Variable	Equipment Recommendations	Major Site Problems/Considerations
Accessibility	• Remote wooded site may require clearing, grubbing, and road construction; crawler tractors, dozers, and scrapers would be used • If site is readily accessible, rubber-tired vehicles should be used because of their higher efficiency • Congested urban sites require use of small equipment, such as forklifts and bobcats; may require use of slings or yokes attached to backhoes or crane if drums are located in a warehouse or building • Industrial vacuum loaders with long hoses (up to 150 m or 500 ft) can be useful in removing soil around drums in areas that are inaccessible to large excavation equipment	• In remote wooded sites, geophysical testing should be conducted prior to clearing and road construction to minimize the possibility of rupturing drums with equipment • Population and worker exposure are of particular concern in congested areas; extensive air monitoring is required
Number of Drums	• Where a large number of drums are involved, use high-production equipment, such as the barrel grappler and industrial vacuum loaders • Where few drums (< 500) are involved, efforts should be made to limit the number and types of equipment; front-end loaders and bobcats may be suitable at small sites, but the condition of the drums must be considered in selecting appropriate equipment	• Economics are a major concern where large numbers or small numbers of drums are involved; however, worker safety is not compromised in efforts to save money

(continued)

TABLE 15. (continued)

Site Variable	Equipment Recommendations	Major Site Problems/Considerations
Drum Integrity	• The barrel grappler is recommended, however, liners or dikes should be used in the work area to contain spills if drums rupture; work areas should be diked and plexiglas shields should be used on vehicle cabs; drums should be handled individually to avoid mixing incompatible wastes; highly overpressurized drums should be isolated by barriers and vented before handling • Where drum integrity is poor, contents should be transferred or drums overpacked rather than hauled	• Worker safety and environmental releases are of overriding concern; every effort should be made to avoid mixing incompatible wastes and handling explosives or overpressurized drums
Water Table	• If water table is high, site may require drainage prior to drum handling • Crawler-mounted vehicles or flotation tires are recommended for swampy, marshy areas; swamp pads and timber mats may improve accessibility • Where water table is low, rubber-tired vehicles can generally be used efficiently	• Contamination of water and groundwater • Drum integrity is likely to be poor where drums have been in contact with water
Highly Toxic/ Hazardous	• Where highly toxic materials are being handled, the operation should be as remote as possible; the drum grappler should be used where possible with precautions taken to contain spills within the work area	• Worker safety and environmental releases are an overriding concern

(continued)

TABLE 15. (continued)

Site Variable	Equipment Recommendations	Major Site Problems/Considerations
Highly Toxic/ Hazardous (continued)	• Radioactive, explosive, and shock-sensitive materials should be moved remotely to an isolated staging area.	
	• Where the drum grappler cannot be used, drums should be handled one at a time; where a backhoe is used, nonsparking bucket teeth and a morman bar should be used; splashes in the vicinity of workers should be avoided; if drum grabbers are used for overpacking, workers should leave the immediate vicinity before the drum is lowered into overpack; vehicle operator should be protected by a plexiglas shield	• Where drum integrity is poor, contents should be transferred or drums should be overpacked
Depth of Burial	• Evacuation of subsurface drums generally requires use of a backhoe or grappler; a grappler is more adept at removing drums from parallel trenches, while the conventional backhoe is limited to excavation from above; use morman bars and plexiglas shields on vehicles when dealing with unknowns	• Where drums are buried beneath the surface, contents are frequently unknown requiring that all safety precautions be taken; although geophysical surveying may have been done, exact location of drums is not a certainty
	• Drums that are very deep may require use of a clamshell or dragline during excavation	
	• Drums on the surface can be handled using loaders and forklift trucks providing drum integrity is good	

The final factor that influences the selection of equipment is the cost to complete the cleanup. Factors that should be considered in estimating costs include:

- Equipment efficiency under site-specific conditions
- Equipment dispatching time (transport and setup)
- Contractor performance record with equipment
- Equipment idle time and how it can be minimized
- Equipment versatility to perform several functions
- Adaptation of equipment to increase efficiency.

EXCAVATION/REMOVAL PROCEDURES

Regardless of the type of equipment used for drum excavating and handling, certain standard operating procedures and safety practices should be followed.

As the soil around the drum is excavated with nonsparking hand tools or an industrial vacuum and the face of the drum is exposed, a visual inspection of the drum is made to determine whether it is empty, intact, leaking, or potentially dangerous, as evidenced by bulking, buckling, corrosion, and other deformations. Onsite monitoring should also be done to determine unsafe levels of volatile organics, explosives, or the presence of radioactive materials (Section 6). This preliminary visual inspection is the basis for determining the appropriate mode of excavating and handling.

Drum identification and inventory (Section 8) should begin before excavation. Information such as location, date of removal, drum identification number, overpack status, and any other identification marks should be recorded on the drum inventory forms.

Handling Precautions for Specific Waste/Container Types

If there is an indication that the drums contain explosive or shock-sensitive materials, they should be handled remotely, or as a minimum, with vehicles equipped with plexiglas safety shields. It is important to be able to identify types of drums as possibly containing explosive materials. For instance, one cleanup contractor observed that drums without rolling hoops that are not Department of Transportation (DOT) specification drums are frequently of military origin and are likely to contain explosives or nerve gas. Also, small (5 gallon) pails, because of their convenient size, are probably lab packs (personal communication with F. Klotzbach, SCA, Inc., Boston, MA, 1982).

If a drum is critically overpressurized, it should be isolated with a barricade or steel demolition net until the pressure can be relieved remotely (Section 8, Drum Opening Tools). If it is not possible to set up a barricade, a tarpaulin may be used to cover the drum, provided the cloth is positioned remotely using long poles or rods. However, it must be cautioned that the mere weight of the tarpaulin or change in position of the drum could cause rupture. Slow venting using a bung wrench and plastic cover over the drum has worked for less critical situations; however, this should only be attempted by experienced personnel and extreme caution should be exercised.

Drums containing ionized levels of radiation should be handled on a site-specific basis. Generally, when such drums are identified (via radiation meters), they are immediately overpacked using remotely operated equipment and moved to a separate staging area. However, depending on the level of radiation, special shielding devices may be required to protect field personnel. The Safety Officer should be consulted if radioactive material is encountered. To avoid tracking the radioactive material about the site, the equipment used in handling the drums must be decontaminated, and any radioactive soils immediately surrounding the drum should be excavated and isolated.

If gas cylinders are encountered, they should be moved promptly to an area where the temperature can be controlled, particularly if they are subjected to temperature extremes or direct sunlight. Gas cylinders should not be rolled, dragged, or slid, even for short distances. Care should be taken not to drop the cylinders or allow them to violently strike another cylinder or drum (Matheson Gas Products, undated).

As contaminated soils are excavated from the disposal area, they should be transferred to a temporary storage area, preferably a diked or bermed area lined with plastic or low permeability clays. A layer of absorbent should be placed on the bottom of the diked area.

Handling Drums with Poor Structural Integrity

Any drum that is leaking, badly corroded, or deformed either should be overpacked or the contents transferred, by pumping, to a new or reconditioned drum. If the drum has a small puncture or leak, it may be possible to use wooden plugs, neoprene stoppers, etc., to temporarily plug the leak. Wooden, felt-covered plugs are most effective because the wood and felt expand to contain the leak. In some instances, it may be possible to transfer the drum contents to a "compatibility" chamber or vacuum truck. These procedures, however, are usually used for bulking after wastes have been identified (Section 9) rather than at this stage, since lack of knowledge about waste types could result in incompatible waste reactions.

As a rule, liquids contained in drums that are leaking or highly deteriorated should be immediately transferred to a new or reconditioned drum. Leaking drums containing sludges or semisolids, drums that are structurally sound but opened, or drums that are deteriorated but moveable may be overpacked.

It is generally safer to pump the contents of a structurally poor drum into a new drum, since maneuvering the drum into an overpack may cause rupture. Pumping is usually done with a skid-mounted vacuum pump. Since the drum contents are unknown, it is necessary to use explosion-proof, chemically resistant pumps and to decontaminate the pump and hosing between transfers to avoid incompatible waste reactions.

Overpacking requires considerable skill on the part of the equipment operator because of the narrow clearance between the overpack and the drum. Attachments suitable for overpacking include the backhoe-mounted grapple arm and forklift trucks equipped with drum grabbers (Figures 23 and 24, respectively). The grabbers, however, do not have the flexibility for lowering the drum into the overpack; consequently, their use may cause the drum contents to splash out. Where the drums are slightly bent or dented, the dexterity of the grappler arm is particularly important for successful overpacking. Severely bent or dented drums, however, are not suitable for overpacking.

When liquids are being removed from a drum by pumping, a ground must be established between the drum and the receiving container if the container is metallic, or to a ground stake if the receiving container is not metallic. Such grounding will eliminate the buildup of significant static charges. If the liquid, such as a solvent, does not conduct electricity, a very thin area where the solvent and the wall of the drum touch has an electrical imbalance. When the solvent leaves the drum through a spout or bung hole, it carries some electrical charge. The drum is left with a small and opposite electrical charge, which increases as more solvent is drawn from it. If this charge becomes large enough and the drum comes in close contact with another surface such as the container or vessel to which the waste is being transferred, a spark can result causing a fire or explosion. Any spills that occur when drums rupture should be cleaned up promptly using pumps or sorbent materials.

Case Histories

A few case histories are presented below to illustrate the use of equipment for drum excavation, staging, and hauling. Other operational aspects of these case studies (i.e., sampling, recordkeeping, etc.) are not discussed.

At the Chemical Control site in Elizabeth, New Jersey, O.H. Materials Company used forklifts, front-end loaders, a barge-mounted crane, a specially developed barrel grappler, and a team of 71 workers to remove over 40,000 drums, many of which were badly charred and damaged by a large explosion and fire. The crane and grappler were used to lift and relocate drums piled six to ten high at the congested site. The grappler was able to remove and stage as many as 1,000 drums each day. Forklifts equipped with drum grabber attachments were initially employed to remove and overpack scattered, damaged drums and provide working space for the grappler and loader operations. Some liquid from leaking drums spilled out during overpacking. Once the stacked drums were reduced to one to two layers, front-end loaders were used to segregate drums by waste type (solid, liquid, sludge) for subsequent sampling and analysis. Field crews often had to lift the damaged drums onto the loader buckets by hand. Extensive manual handling of drums was also required

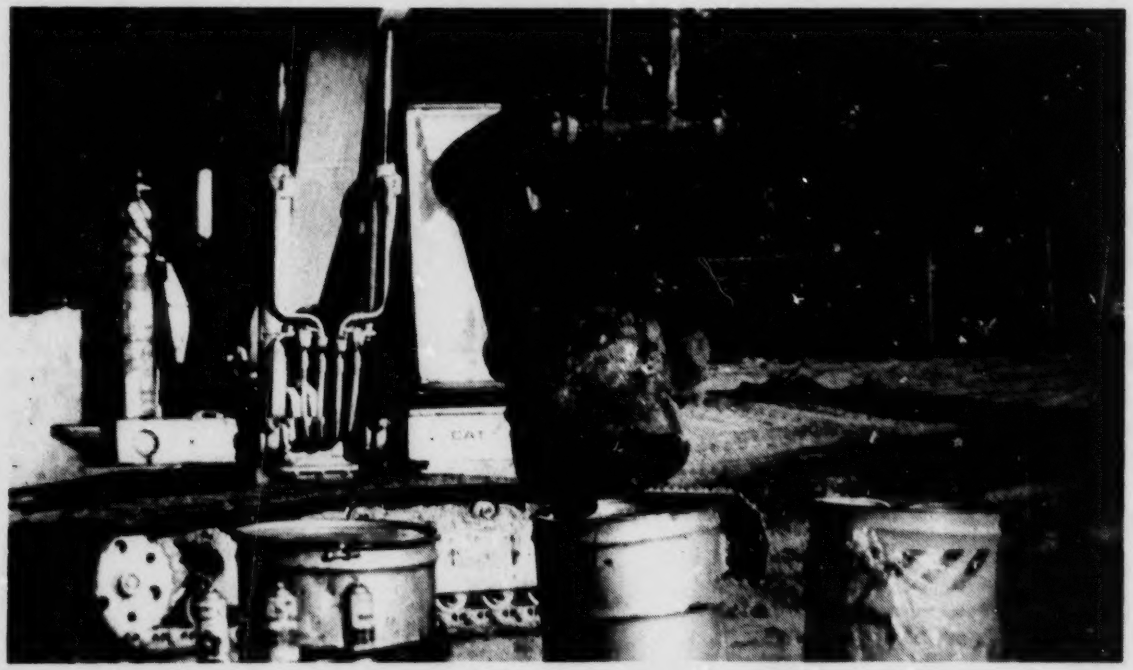


Figure 23. Use of the Grappler Attachment for Overpacking Drums

(Courtesy of O.H. Materials, Findley, OH)

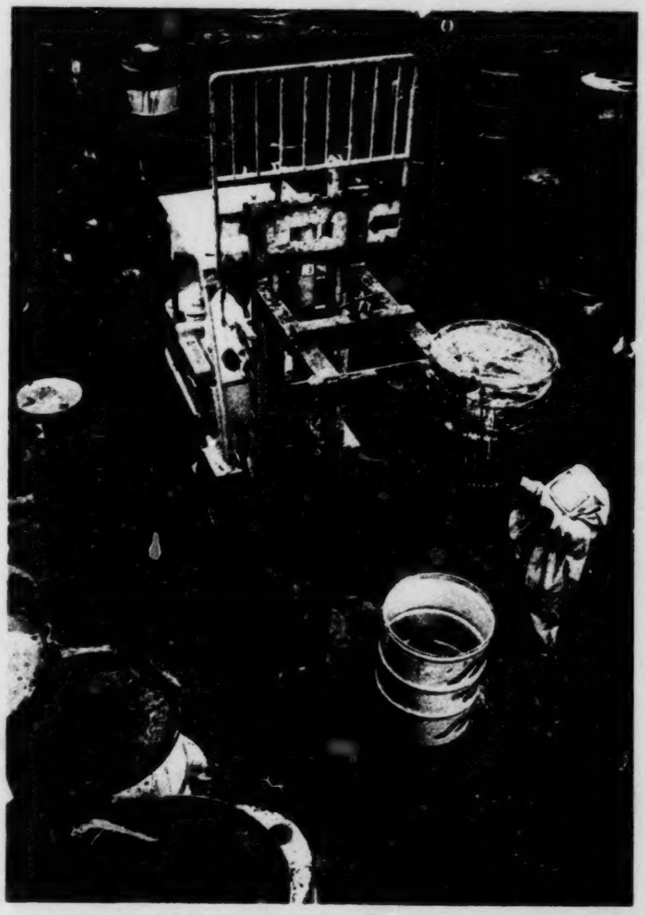


Figure 24. Use of Forklift Grappler Attachment for Overpacking

(Courtesy of Pollution Engineering Magazine) for the crane lifting operation. Empty, damaged drums were crushed with backhoe and loader buckets and disposed of as bulk contaminated solids. Hydraulic compactors were also used by O.H. Materials for drum crushing and solids compaction. (EPA Environmental Response Team, Video Tapes of Chemical Control Site Cleanup) (Finkel and Golob, 1981).

At the 3.2-hectare (8-acre) Picillo Farm dump site in Coventry, Rhode Island, Peabody Clean Industries and R.J. Corman removed approximately 5,000 drums from excavated trenches using a barrel grappler, crawler loaders, and backhoes (both crawler-mounted and rubber-tired). The grappler was also used to excavate and remove over 100 lab packs and proved very efficient and dexterous. Drums were excavated at several angles from an open trench and placed directly in a staging area with very little shock to the drums. The lab packs were segregated and field workers repacked them. Rubber-tired backhoes then hauled the drums to temporary storage. (EPA Environmental Response Team, Video Tape of Picillo Farm Site Cleanup.)

Drum handling operations at the Gilson Road Hazardous Waste Disposal Site in Nashua, New Hampshire, involved the removal of approximately 1,400 drums from four disposal areas. For the most part, the drums had been disposed of on the surface or partially buried. This site was inaccessible to some of the heavy equipment required for drum removal and an access road had to be constructed. The drums were individually handled and moved to a staging area using a heavy-duty forklift truck with a chain or set of drum-lifting hooks. Before moving, each drum was visually inspected to check for drum integrity. Leaking drums were transferred or overpacked. A drum grabber attachment was also available for the forklift truck. However, the grabber was not effective in removing drums from the pile because of the haphazard manner in which the drums had been disposed and because, in many instances, the drums were stuck together. Both the drum grabber attachment and the drum-lifting hooks were used to segregate the drums into compatible waste classes, overpack damaged drums, and load the drums onto flatbed trucks (Recra Research Inc., 1980).

As these case studies illustrate, drum handling efforts typically involve the combined use of several equipment types, and in the absence of the grappler, require close contact between workers and drums in loading or attaching the drums onto buckets, grabbers, etc. Drum removal equipment must dig, grab, lift, load, haul, and manipulate drums. These functions generally require the use of at least two or three different machines in addition to hand tools or the assistance of site workers. However, the versatile barrel grappler often eliminates the need for direct manipulation by field personnel. Again, the most efficient and cost effective combination of equipment types is determined by site-specific conditions and required activities.

SECTION 8

DRUM STAGING, OPENING AND SAMPLING

STAGING

Once a drum has been excavated and any immediate hazard has been eliminated by overpacking or transferring the drum's contents, the drum is affixed with a numbered tag and transferred to a staging area. Color-coded tags, labels, or bands could be used to mark similar waste types.

A description of each drum, its condition, any unusual markings, and the location where it was buried or stored are recorded on a drum data sheet similar to the one shown in Table 16. This data sheet becomes the principal recordkeeping tool for tracking the drum onsite. A separate drum/bulk sheet is also required for laboratory analysis and offsite transport (manifest) of the wastes.

When a large number of drums is involved, a computerized data retrieval system should be considered to provide instant information on drum location, waste type, and current inventory of similar drums via search programs. If a computerized data system is not practical or feasible, forms should be prepared showing the layout of each storage area. The drum identification number and color code should then be marked on the form.

In many instances, the state, or responsible party, also requires that the drums be photographed (before overpacking or transferring), particularly if they have identifying marks.

Ideally, the staging area(s) should be located just far enough from the drum opening area to prevent a chain reaction if one drum should explode or catch fire when opened. The area should be free of debris and arranged so that vehicles can access the drums easily for transfer to the drum or consolidation opening area (Figure 25). Secondary containment measures for staging areas are described in Section 5. If the site is located in an area with a high water table, low flatbed trucks may be adapted for staging. If the site is located in a confined or congested area, the possibility of excavating, staging, opening, and bulking the drums in shifts should be considered. If drums have been stored in a warehouse, the warehouse may serve as the staging area, providing there is adequate ventilation and space available for drum handling equipment and emergency evacuation in case of fire or explosion.

During staging, the drums, or other containers, should be physically separated into the following categories when possible: those containing

TABLE 16. DRUM/BULK DATA FORM

Sampling   Date Sampled: ____________

Drum ID#: ______________________   Time: ____________________

Estimated Liquid Quantity: __________

Grid Location*: ____________________

Staging Location: ____________

Sampler's Name: ___________________

Drum Condition: ___________________

Physical Appearance of the Drum/Bulk
Contents: ________________________

Odor: ____

Color: ____

pH: __________________________   % Liquid: ________________

Laboratory   Date of Analysis: ____________
Analytical Data: ____

Compatibility: ____

Hazard: ____

Waste ID: ____

Treatment Disposal Recommendations: ___________________________________

Approval

Lab: __________________________   Date: ________________

Site Manager: ___________________   Date: ________________

---

*Area of site where drum was orginally located

Based on DiNapoli, 1982. Table originally printed in the Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982. Available from Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, MD 20910.

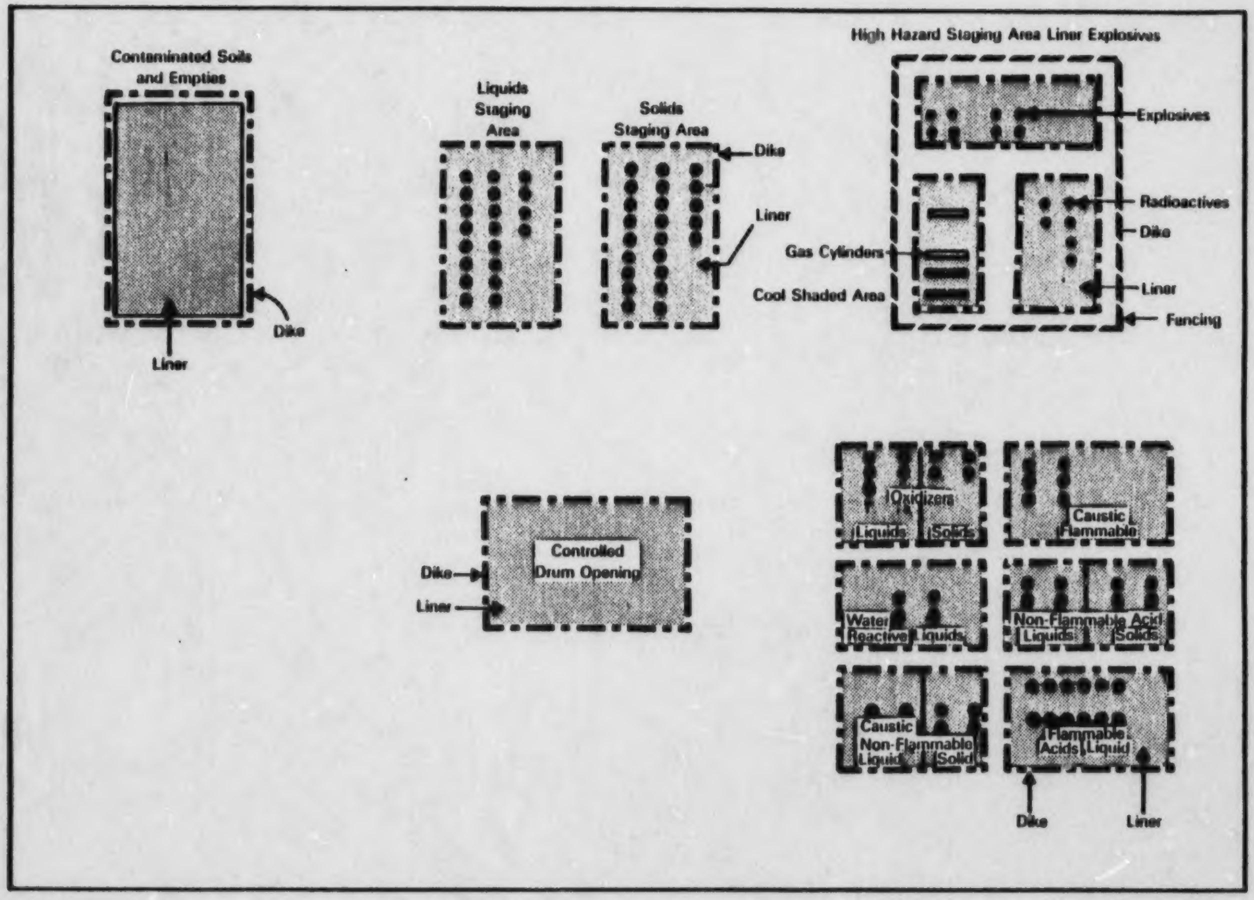

Contaminated Soils and Empties
Liner
Dike
Liquids Staging Area
Solids Staging Area
Dike
Liner
High Hazard Staging Area Liner Explosives
Explosives
Radioactives
Dike
Gas Cylinders
Cool Shaded Area
Liner
Fencing
Controlled Drum Opening
Dike
Liner
Oxidizers
Liquids
Solids
Caustic Flammable
Water Reactive
Liquids
Non-Flammable Acid
Liquids
Solids
Caustic Non-Flammable
Liquid
Solid
Flammable Acids
Liquid
Dike
Liner

Figure 25. Layout for Separate Drum Staging and Opening Areas

liquids, those containing solids, lab packs, gas cylinders, and empties, since the strategy for sampling and handling drums/containers in each of these categories is different.

Where there is a good reason to suspect that drums containing radioactive, explosive, and shock-sensitive materials are present, these materials should be staged in a separate, isolated area if possible (Figure 25). Placement of explosives and shock-sensitive materials in diked and fenced areas will minimize the hazard and the adverse effects of any premature detonation of explosives.

The process of staging drums is rarely straightforward. Segregating drums into liquids, solids, and drums containing assorted laboratory containers may require use of one or more of the following methods:

- Visual inspection of the drum and its labels, codes, etc. Solids and sludges are typically disposed of in open top drums (i.e., with bolted rings). Closed head drums with a bung opening generally contain liquid.
- Tapping on the drum by hand or with a brass tool, to determine the category by sound.
- Visual inspection of the contents of the drum during sampling, followed by restaging, if needed.

Several cleanup contractors expressed concern over the practice of tapping drums to determine their contents. This approach is neither uniformly safe nor effective and should not be used if the drums are visually overpresssurized or if shock-sensitive materials are suspected.

The use of nondestructive test methods as an alternative for determining whether a drum contains liquid or solid has been investigated. Ultrasonics has been found to be unsuitable for this purpose, because it requires that the surface of the drum be clean and free of chipping paint and debris (Lord, Tyagi, and Koerner, 1981). Highly sensitive infrared scanners can distinguish solids, liquids, and air inside containers based on their thermal conductivity. However, this method requires that the drum be heated and the pattern of cooling observed. Such an approach would obviously be unsafe where drums containing unknown wastes are involved (Greenhalgh, 1980).

DRUM OPENING

Drum Opening Area

Where space allows, the drum opening area should be physically separated from the drum removal and drum staging operations, as mentioned previously.

There should be sufficient distance between the drum opening and the removal and staging operations to prevent a chain reaction or fire during drum opening (CMA, 1982).

A drum opening bunker should be constructed at sites where drum integrity is poor and drum contents are highly toxic, explosive or reactive. The bunker is an isolated area surrounded by sandbags, earthen dikes or cinder blocks and lined with plastic, concrete, etc. The pad should be sloped so that spills flow toward a central collection sump. Alternatively, the drum may be placed in a pan that has adequate volume to recover any spillage in case the drum ruptures (CMA, 1982). The pan should have a drain for recovering the wastes. Further protection should be provided for field workers by using a plexiglas shield that they can step behind when opening drums. Sensors and probes for direct reading of air monitoring equipment should be located near the drum opening equipment, and the meters should be situated behind the plexiglas shield. A laboratory scale gas scrubber could be installed in the opening area for recovering vented gas.

Drums are moved from the staging area to the drum opening area one at a time using forklift trucks equipped with drum grabbers or the barrel grappler. In a large-scale drum handling operation, drums may be conveyed to the drum opening area using a roller conveyor.

Combined Drum Staging/Drum Opening Areas

At some sites where the work space is too confined or where the logistics of marshalling thousands of drums from a staging area to a drum opening area is cost prohibitive, cleanup contractors have used a combined drum opening/staging area rather than the separate staging and opening areas discussed previously. Using this approach, drums are staged in rows of two or in groups of four, with sufficient distances between each row or group to provide easy access for drum opening equipment and adequate space for emergency evacuation in the event of fire or explosion. A spacing of 0.3 to 0.5 meters (1-1.5 feet) or more is provided between each drum in a row to minimize the possibility of chain reactions in the event of explosions or fires. A layout of this type of combined staging/opening operation is shown in Figure 26. This method was used in the cleanup of drums at the General Disposal Company in Santa Fe Springs, California, to provide for rapid, remote opening of drums and to eliminate the need to relocate the barrels (Buecker and Bradford, 1982).

Drum Opening Equipment

There are three basic techniques available for drum opening at hazardous waste sites:

- Manual opening with nonsparking bung (or plug) wrenches
- Drum deheading
- Remote drum puncturing or bung removal.

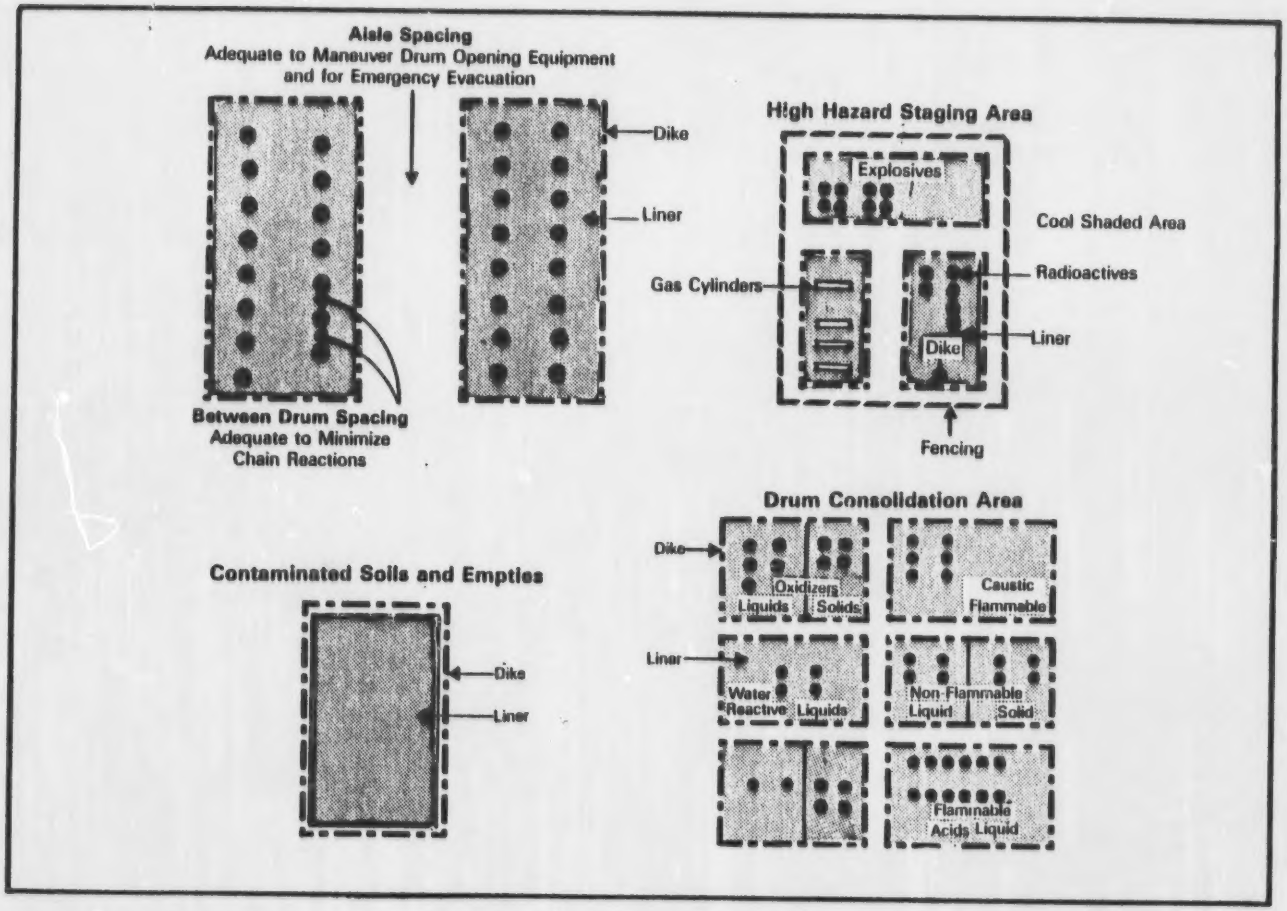

Aisle Spacing
Adequate to Maneuver Drum Opening Equipment and for Emergency Evacuation
Dike
Liner
Between Drum Spacing Adequate to Minimize Chain Reactions
High Hazard Staging Area
Explosives
Cool Shaded Area
Gas Cylinders
Radioactives
Liner
Dike
Fencing
Drum Consolidation Area
Dike
Oxidizers
Liquids
Solids
Caustic
Flammable
Liner
Water Reactive
Liquids
Non-Flammable
Liquid
Solid
Flaminable
Acids
Liquid
Contaminated Soils and Empties
Dike
Liner

Figure 26. Layout for Combined Drum Staging and Opening Areas

The choice of drum opening techniques and accessories largely depends on the number of drums to be opened, their waste contents (if known), and their physical condition. Remote drum opening equipment should always be considered in order to protect worker safety, especially if the drums are damaged or corroded. Manual opening with bung wrenches or drum deheaders should be performed only with structurally sound drums with waste contents that are known to be nonreactive and nonexplosive.

Hand Wrenches--

If closed head drums are present, access for sampling or removing the contents is most conveniently obtained by removing the bung plug located on the head or side of the drum. Bung plugs are threaded plugs of various design, and there are a number of commercially available "universal" bung wrenches suitable for bung removal (Figure 27).

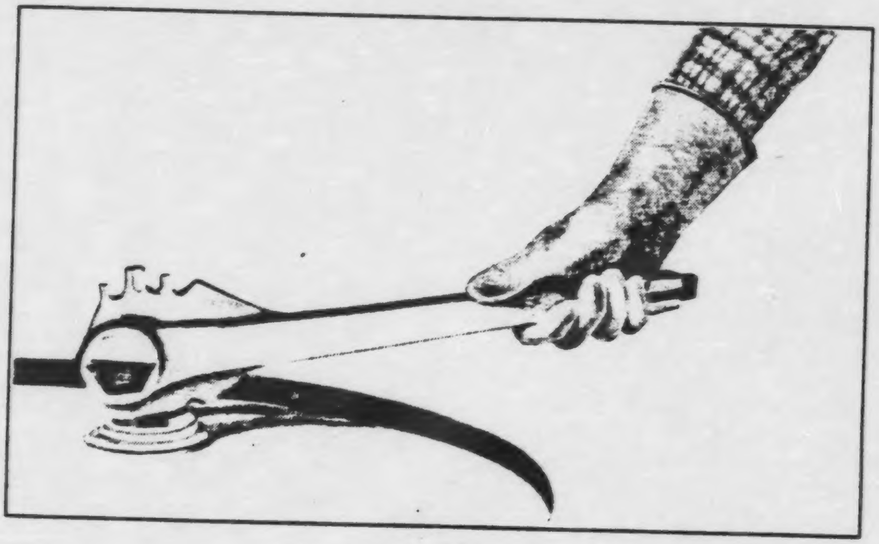


Figure 27. Nonsparking Bung Wrench
(Courtesy of Wizard Drum Tools,
Hydrothermal Corporation, Milwaukee, WI)

Bung wrenches should be of nonsparking metal alloy construction (bronze/manganese, aluminum, molybdenum) to eliminate the potential explosions posed by certain waste types or pressurized gases and liquids. This tool is generally available for about $20 (Arrow Star Inc., 1981; INTEREX Safety Supplies, 1982).

Again, manual drum opening with bung wrenches should not be performed unless the drums are structurally sound (no evidence of bulging or deformation) and their contents are known to be nonexplosive. If opening the drum with bung wrenches is deemed reasonably cost-effective and safe, then certain procedures should be implemented to minimize the hazard. Field personnel should be fully outfitted with protective gear. Drums should be positioned upright with the bung up, or, for drums with bungs on the side, laid on their sides with the bung plugs up. The wrenching motion should be a slow, steady pull across the drum. If the length of the bung wrench handle provides inadequate leverage for unscrewing the plug, a "cheater bar" can be attached to the handle to improve leverage. If there is evidence of incompatible chemical reactions, sudden pressure buildup, or a release of potentially toxic fumes while the bung is being loosened, field personnel should immediately leave the area and arrange for remote drum opening equipment to be used. If the drum plug cannot be opened successfully using a nonsparking hand wrench, then other methods of drum opening (deheading or puncturing) must be considered.

Drum Deheading--

Wizard Drum Tools manufactures manually operated drum deheaders (Figure 28), which act as "can openers" to cut away the heads of steel drums. Manually deheading a drum is time consuming and inefficient, but it may be desirable for opening small numbers of drums. Manual deheaders are unsafe under many conditions since they require that the worker be close to the drums being opened. The manual deheader illustrated in Figure 28 is manufactured by Wizard Drum Tools and can be purchased for about $315 (Hydrothermal Corporation, 1981).

Wizard Drum Tools also manfactures a portable, self-propelled drum opener (Figure 29) for quicker and more efficient deheading. It may be either electrically or pneumatically driven and is available for about $1,000 (Wizard Drum Tools, 1981). The opener can be attached to a support tower via a chain attachment on a roller sheave (Figure 30). This allows the opener to rotate around the drum head with minimal manual assistance. The equipment is generally set up and operated manually. It could be operated remotely as well, although this would require modification to the existing equipment.

A problem frequently encountered when using a drum deheader or self-propelled opener is that the equipment cannot cut away those parts of the drum head that have been dented or otherwise distorted. The deheader must be frequently readjusted and/or the drum chimes must be undented. A drum dekinker (Figure 31) can be used to manually straighten dented chimes for easier deheading and to reseal leaking drum heads. However, its operation also requires working near potentially hazardous drums.

Remote Drum Opening--

Remotely operated drum opening tools are the safest available means of drum opening. Two basic tools, originally developed by EPA's National Enforcement Investigation Center (NEIC) and since modified by several cleanup contractors, are available. Remote drum opening is slow but provides a high degree of safety compared to manual methods of opening. The remote "bung remover" is essentially an air impact wrench that uses a compressed air tank. A specially devised mounting bracket and a nonparking bung socket are used to spin the bung from the top or side of a drum (Figure 32). The second device developed by NEIC is a hydraulic drum plunger that forces a penetrator

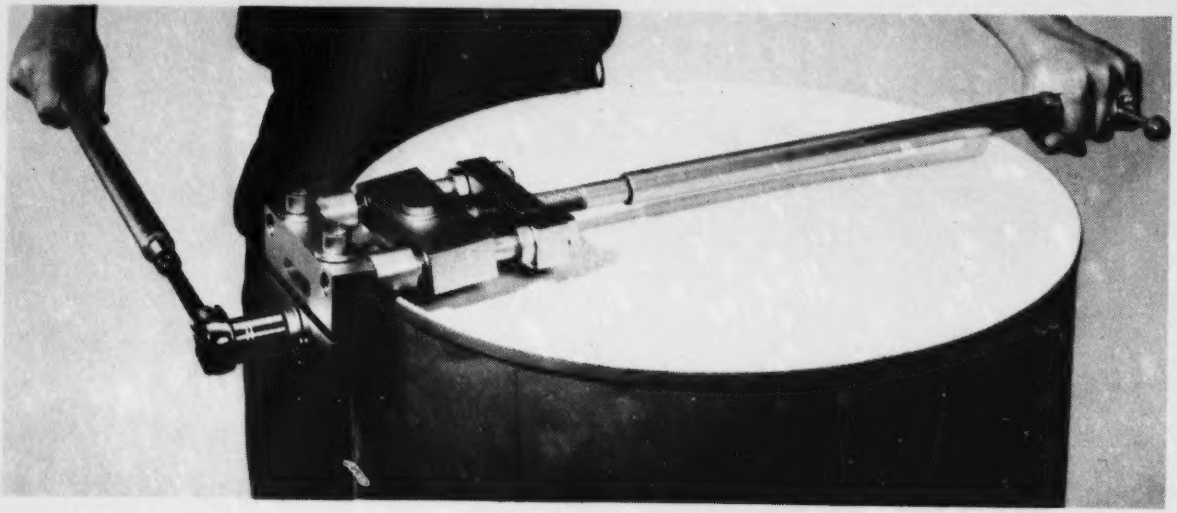


Figure 28. Manual Drum Deheader

(Courtesy of Wizard Drum Tools, Hydrothermal Corp., Milwaukee, WI)

Note: This photograph does not show appropriate safety gear required in the field

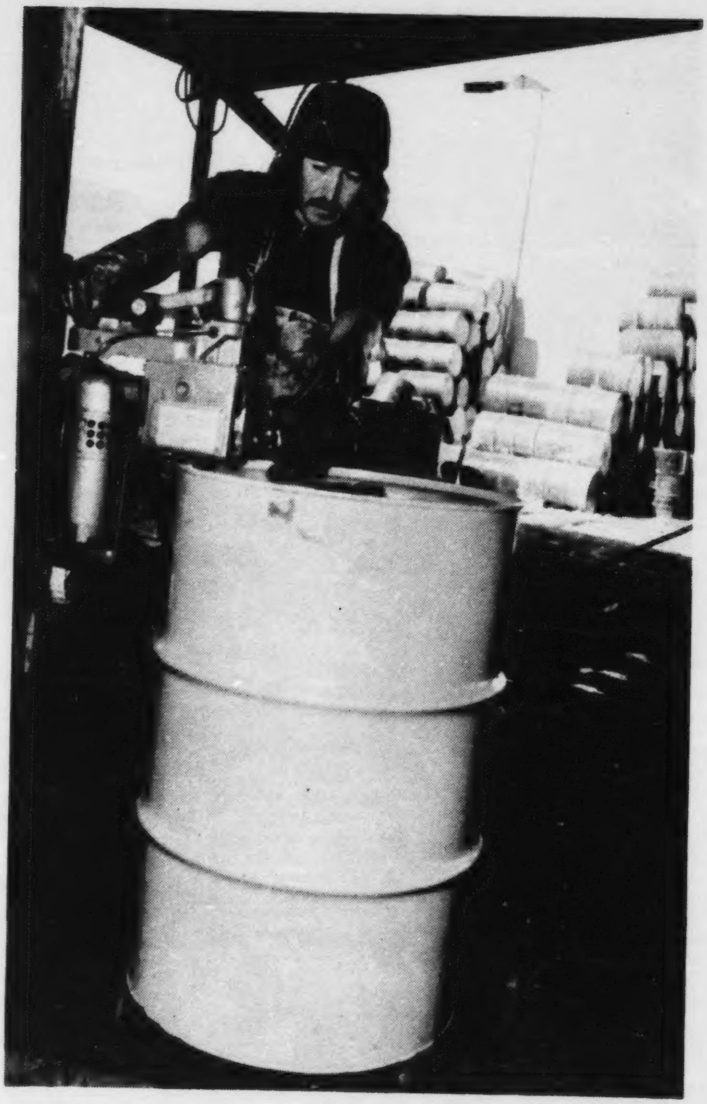


Figure 29. Self-Propelled Drum Deheader
(Electric or Pneumatic Models Available)

(Courtesy of Wizard Drum Tools, Hydrothermal Corportion, Milwaukee, WI)

Note: This photograph does not show appropriate safety gear required in the field

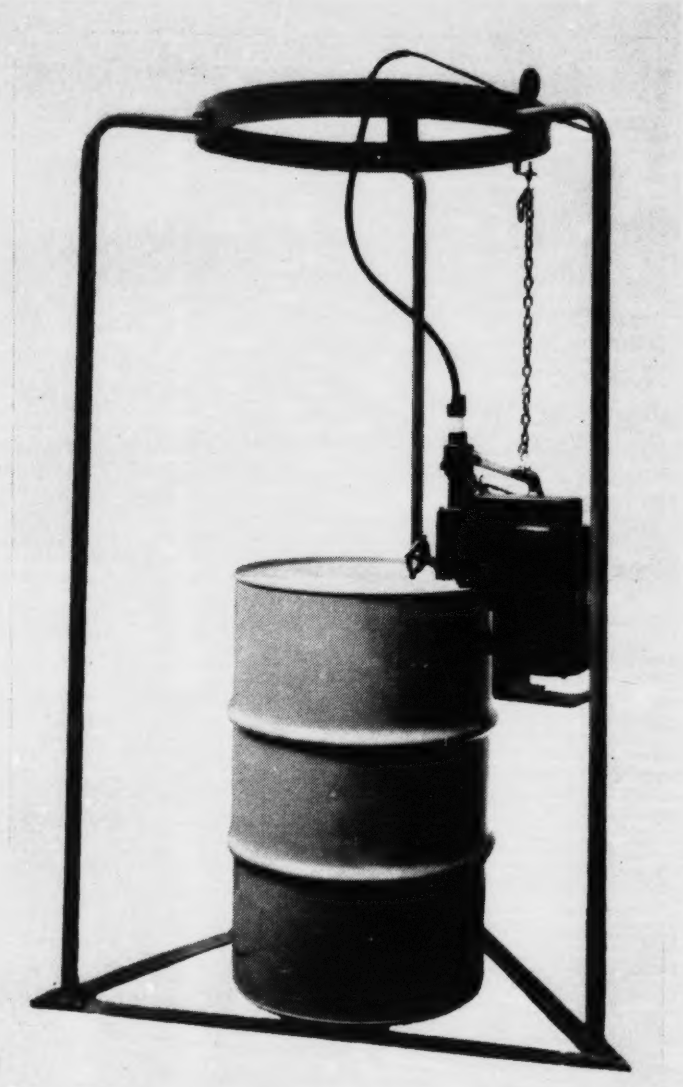


Figure 30. Self-Propelled Drum Deheader with Support Tower

(Courtesy of Wizard Drum Tools, Hydrothermal Corp., Milwaukee, WI)

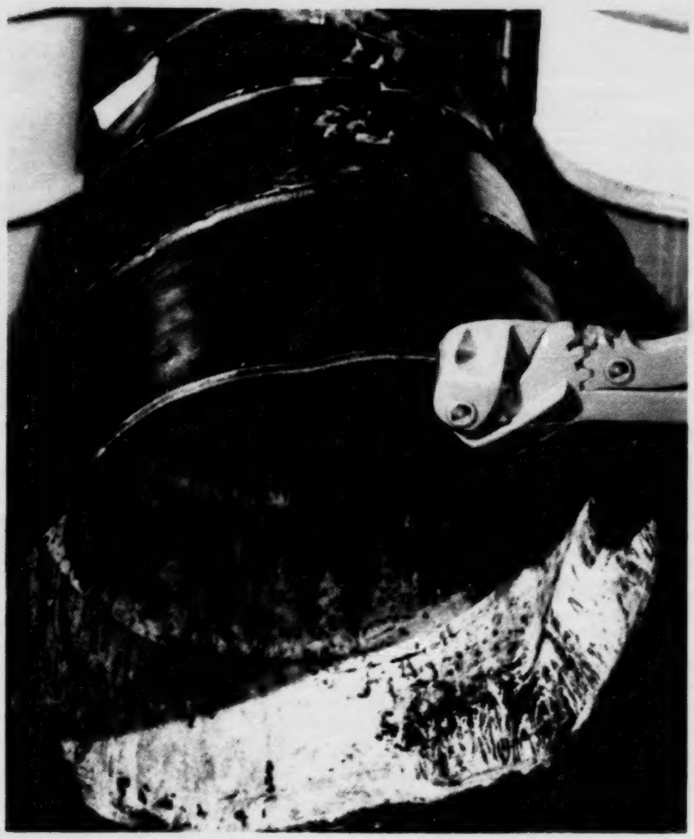
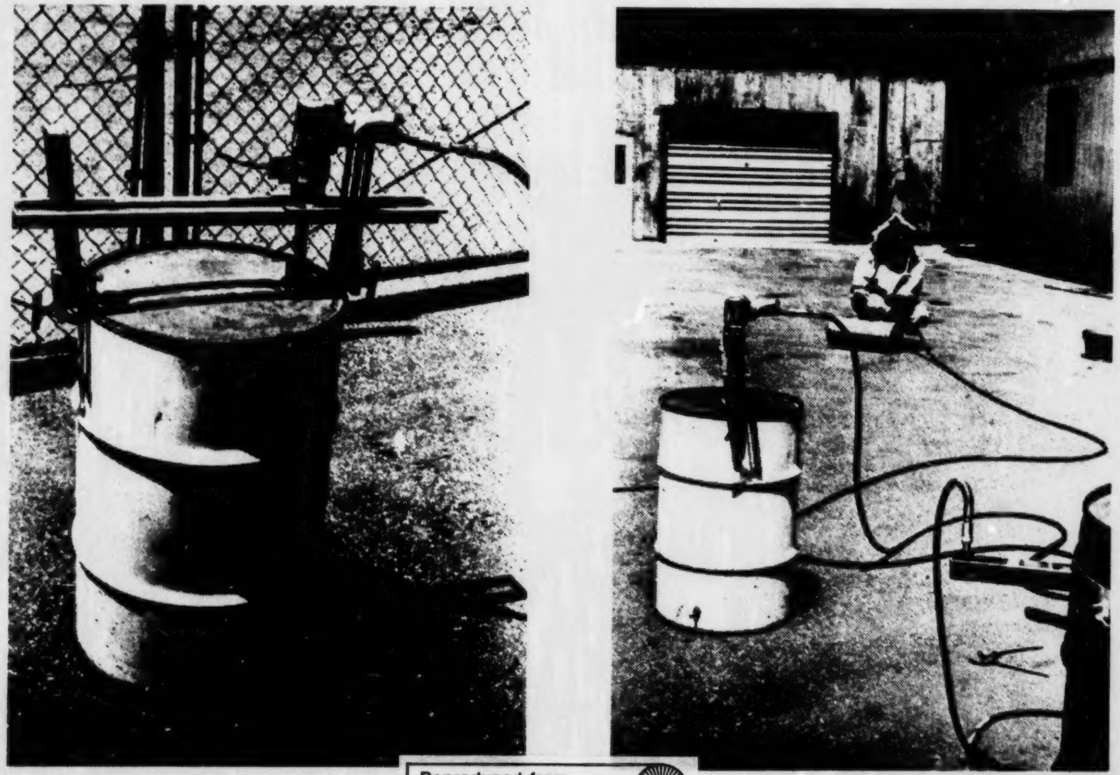


Figure 31. Drum Dekinker

(Courtesy of Wizard Drum Tools, Hydrothermal Corp., Milwaukee, WI)

Note: This photograph is intended only to illustrate drum opening equipment and does not illustrate safety precautions required in the field.



Reproduced from
best available copy.

Figure 32. Pneumatic Bung Wrench: Attachment to Drum and Remote Operation Setup

(Blackman et al., 1980. Figure originally printed in the Proceedings of The National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980. Available from Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, MD 20910.)

into the drums and seals the resulting holes. A sample is withdrawn through the hollow stem of the penetrating device and the device is then left in place to seal the drum (Blackman et al., 1980). The system can be backhoe-mounted (Figure 33) or manually set up (banded or clamped around the drum) for remote operation (Figure 34). The drum plunger may also be incorporated into a mechanized conveyor system (Figure 35) for remote puncturing of a large number of drums in a timely manner (CMA, 1982). NEIC has made the specifications for these pieces of equipment available to several of the EPA Regional Offices. These tools can be developed by making simple and low-cost modifications to existing equipment (Verbal communication with K. Fischer U.S. EPA, NEIC, Denver, Colorado, 1982). As mentioned previously, Wizard Drum Tools' portable, self-propelled drum opener could also be set up to operate remotely provided the chime is free of dents that could cause the opener to stick.

Another technique for drum puncturing involves the use of a nonsparking metal spike attached to a backhoe arm. Figure 36 shows the O.H. Materials barrel grappler holding a drum as it is spiked open with this tool. This method achieves relatively quick and safe drum opening for subsequent sampling, but the nonspecific action of the spike may damage drum integrity. If this method is used, the backhoe boom and dipper assembly should have a relatively long reach (at least 12 meters, or 40 feet), and the backhoe cab should be plexiglas shielded for operator safety. The backhoe spike method for drum opening should be performed by experienced backhoe operators only.

Drums that have been overpressurized to the extent that the head is swollen several inches above the level of the chime should not be moved. A number of devices have been developed for venting critically swollen drums. One method that has proven to be effective is a tube and spear device illustrated in Figure 37. A light aluminum tube 3 meters (10 feet) long is positioned at the vapor space of the drum. A rigid, hooking device attached to the tube goes over the chime and holds the tube securely in place. The spear is inserted in the tube and positioned against the drum wall. A sharp blow on the end of the spear drives the sharpened tip through the drum and the gas vents along the grooves. The venting should be done from behind a wall or barricade (Niggle, 1982). This device could be cheaply and easily designed and constructed where needed. Once the pressure has been relieved, the bung can be removed, the drum sampled, and the bung hole fitted with a pressure venting cap set at 5 psi release. The opening made by tube and spear device should then be sealed.

Table 17 summarizes available drum opening techniques, their recommended applications, and major disadvantages. Remote drum opening via pneumatic bung removal, deheading, or drum puncturing is much more desirable than the manual methods of drum opening discussed previously. They may require more time for drum staging and equipment setup, but they maximize the distance between workers and drums during the potentially dangerous activity of drum opening. Puncturing drums with hand tools and manual bung removal with wrenches or manual deheading is recommended only with structurally sound drums (no bulging, corrosion, dents) with waste contents that are known to be relatively nonhazardous.

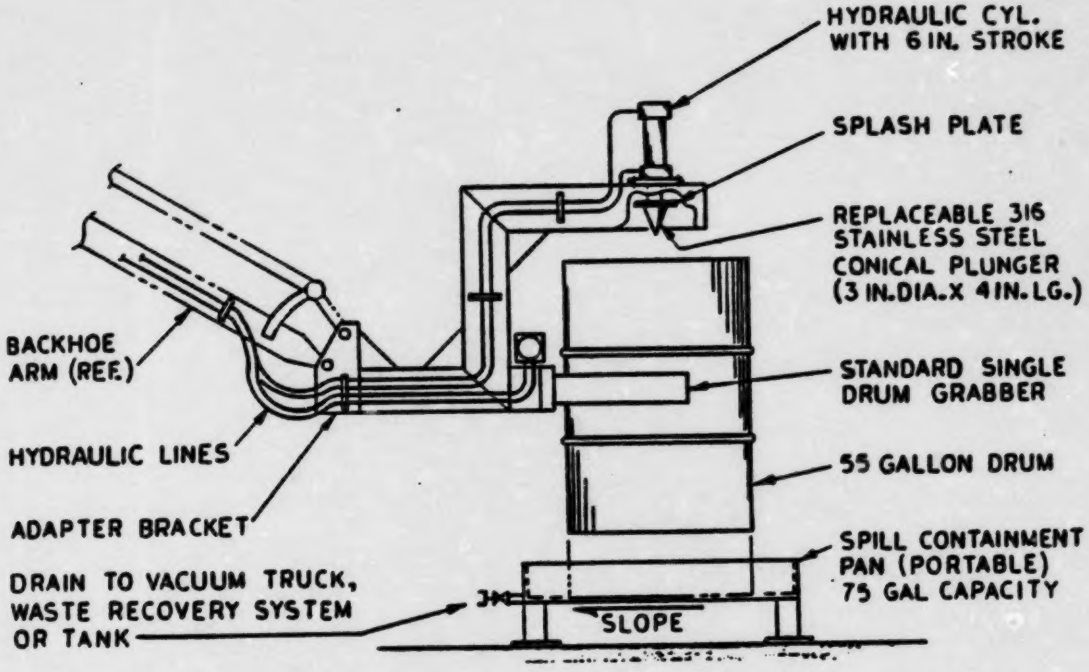

HYDRAULIC CYL. WITH 6 IN. STROKE
SPLASH PLATE
REPLACEABLE 316 STAINLESS STEEL CONICAL PLUNGER (3 IN. DIA. X 4 IN. LG.)
BACKHOE ARM (REF.)
STANDARD SINGLE DRUM GRABBER
55 GALLON DRUM
HYDRAULIC LINES
ADAPTER BRACKET
SPILL CONTAINMENT PAN (PORTABLE) 75 GAL CAPACITY
DRAIN TO VACUUM TRUCK, WASTE RECOVERY SYSTEM OR TANK
SLOPE

Figure 33. Hydraulic Backhoe Drum Plunger Arrangement
(Courtesy of Chemical Manufacturer's Association, Washington, DC)

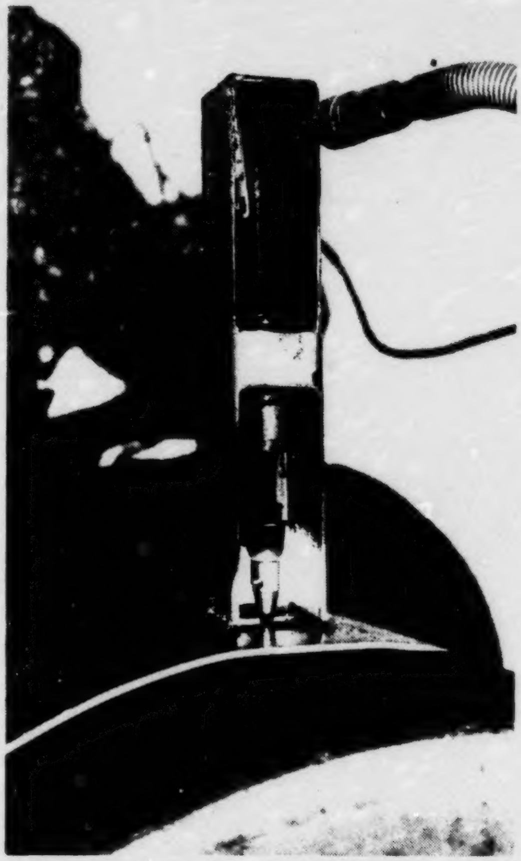
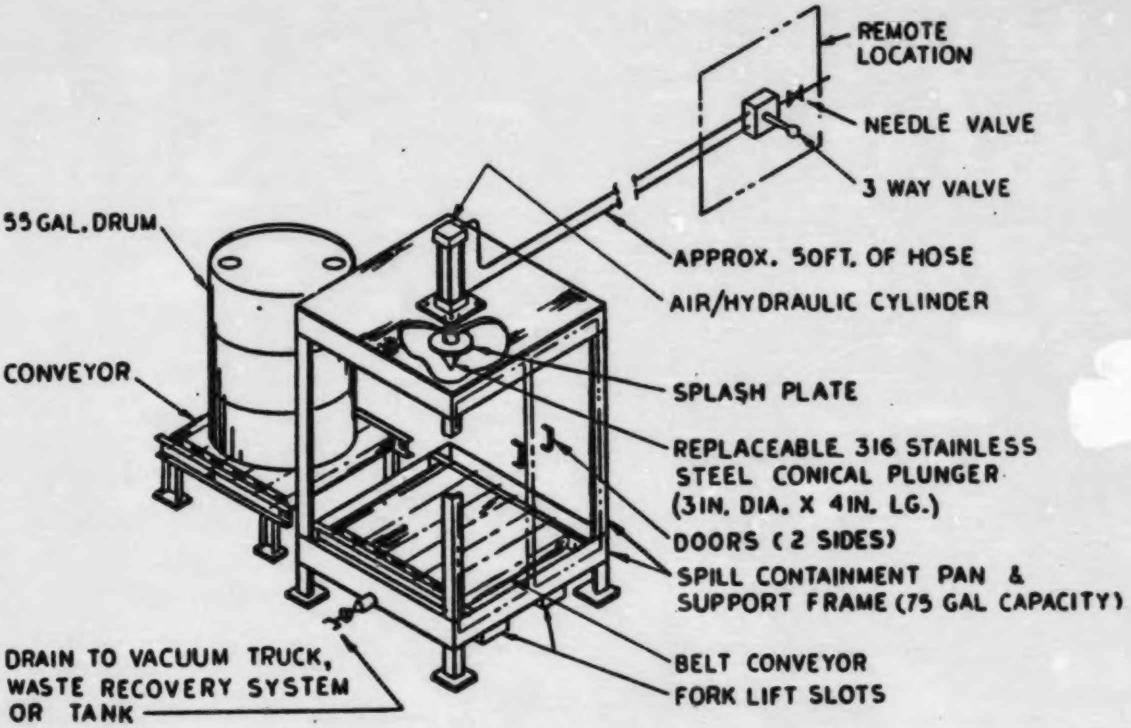


Figure 34. Remote Hydraulic Drum Plunger Mounted on Drum

(Blackman, et al., 1980. Figure originally printed in the Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1980. Available from Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, MD 20910.)


REMOTE LOCATION
NEEDLE VALVE
3 WAY VALVE
55 GAL. DRUM
APPROX. 50FT. OF HOSE
AIR/HYDRAULIC CYLINDER
CONVEYOR
SPLASH PLATE
REPLACEABLE 316 STAINLESS STEEL CONICAL PLUNGER (3IN. DIA. X 4IN. LG.)
DOORS (2 SIDES)
SPILL CONTAINMENT PAN & SUPPORT FRAME (75 GAL CAPACITY)
BELT CONVEYOR
FORK LIFT SLOTS
DRAIN TO VACUUM TRUCK, WASTE RECOVERY SYSTEM OR TANK

Note: A non-sparking, bronze plunger could replace the stainless steel but will be less durable

Figure 35. Conveyor Belt System for Remote Hydraulic Puncturing of Large Number of Drums
(Courtesy of Chemical Manufacturer's Association, Washington, DC)

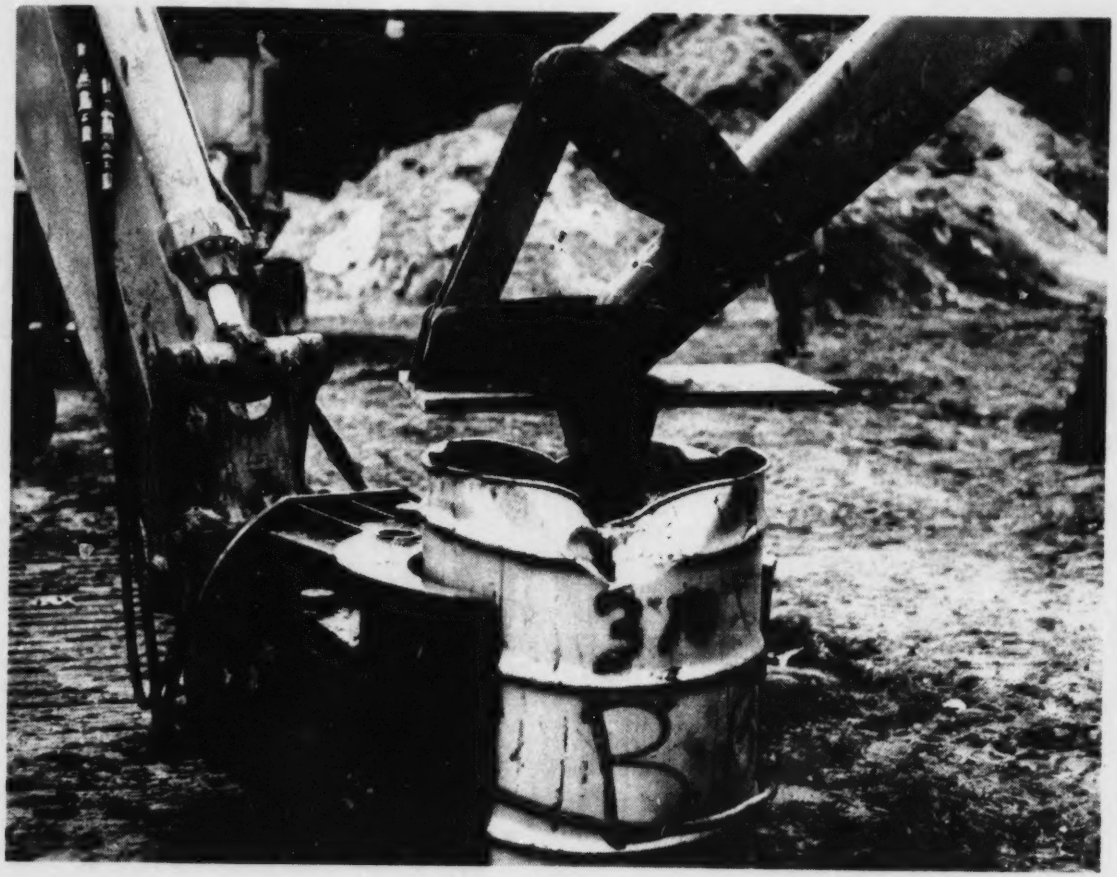


Figure 36. Backhoe Spike (nonsparking) Puncturing Drum Held by Grappler

(Courtesy of O.H. Materials Co., Findlay, OH)

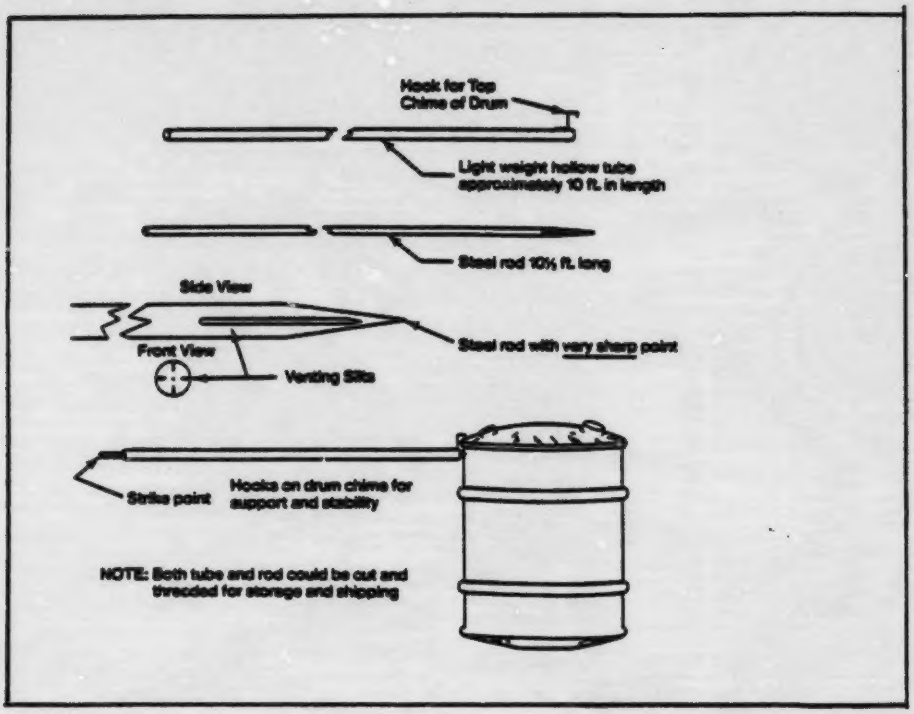

Hook for Top
Chime of Drum
Light weight hollow tube
approximately 10 ft. in length
Steel rod 10½ ft. long
Side View
Steel rod with very sharp point
Front View
Venting Slits
Strike point
Hooks on drum chime for
support and stability
NOTE: Both tube and rod could be cut and
threaded for storage and shipping

Figure 37. Tube and Spear Device Used for Venting Swollen Drums
(Source: Niggle, 1982)
(Reprinted with permission of Government Institutes Inc., Rockville, MD)

TABLE 17. SUMMARY ASSESSMENT OF DRUM OPENING TECHNIQUES

	Recommended Drum Opening Applications (for Sample Acquisition or Recontainerization)								
Technique	Number of Drums to be Opened			Physical Condition of Drums		Waste Content of Drum			Restrictions/Disadvantages
	<100	100-500	>500	Damaged or Bulging	Structurally Sound	Unknown	Shock Sensitive/ Explosive	Non-hazardous	
Bung Wrenches (Nonsparking)	X				X			X	Not recommended for unknown waste contents; full protective gear for worker.
Manual Drum Deheader	X				X			X	Only if bung is impossible to open; used mainly for recontainerization vs. sample acquisition; unsafe if waste contents are unknown.
Self-Propelled Drum Deheader (Electric or Pneumatic)	X				X			X	May require use of a dekinker or readjustment of the deheader if the chime is dented.
Remotely Operated Pneumatic Wrench	X	X		X	X	X	X		Requires direct contact with the drum during attachment of the wrench. Time-consuming setup.
Remote Hydraulic Plunger									Only in controlled area with spill containment.
• Portable	X			X	X	X	X(1)	X	Most time-consuming of the hydraulic plunger methods. Requires direct contact with the drum in order to set up the plunger.
• Self-Propelled (Electric or Pneumatic)	X	X			X	X	X	X	Only suitable if the chime is free of dents.

(continued)

TABLE 17. (Continued)

Recommended Drum Opening Applications (for Sample Acquisition or Recontainerization)

Technique	Number of Drums to be Opened			Physical Condition of Drums		Waste Content of Drum			Restrictions/Disadvantages
	<100	100-500	>500	Damaged or Bulging	Structurally Sound	Unknown	Shock Sensitive/ Explosive	Non-hazardous	
• Backhoe-attached			X	X	X	X	X(1)	X	Use long boom-dipper arms (> 12 meters or 40 feet).
• Conveyor			X	X	X	X	X(1)	X	Has not been used in the field to date.
Backhoe Spike (Nonsparking)	X	X		X		X	X	X	May damage drum; use long backhoe boom (>40').
Tube and spear device for venting	X	X	X	X			X		Method applicable for venting of pressure, but not for drum sampling.

(1) Plunger may be of nonsparking bronze or of stainless steel, which is more durable.

SECTION 9

WASTE CONSOLIDATION AND RECONTAINERIZATION

The activities discussed in this section are designed to achieve two basic objectives:

- Pretreat, bulk, or recontainerize the waste to meet the requirements of the treatment or disposal facility in the most economical way possible

- Put the wastes in a safe and acceptable form for transportation to a permitted treatment/disposal facility.

COMPATIBILITY TESTING

As each drum is opened, it is scanned for radioactivity and, if negative, a sample is taken for compatibility testing. Compatibility testing refers to simple, rapid, and cost-effective testing procedures that are used to segregate wastes into broad categories (i.e., radioactive, oxidative, water reactive). By identifying broad waste categories, compatible waste types can be safely bulked onsite without risk of fire or explosion, and disposal options can be determined without exhaustive and costly analysis of each drum.

Sampling is conducted using a sampling thief for liquids and a coring tool for solids. Solid samples should be taken from several different areas within the drum. In addition, the contents of all drums should be described on the drum data sheet in terms of physical state, viscosity, and number of phases. A sample must be taken for each phase.

Compatibility testing protocols have been developed by a number of cleanup contractors and waste generators. Often, however, the compatibility testing procedures must be tailored for site-specific conditions or to meet the testing requirements of prospective treatment/disposal facilities. A thorough compatibility testing protocol, developed by Chemical Manufacturers Association (CMA) (1982) is outlined in Figure 38. This protocol has been used in a number of cleanup operations.

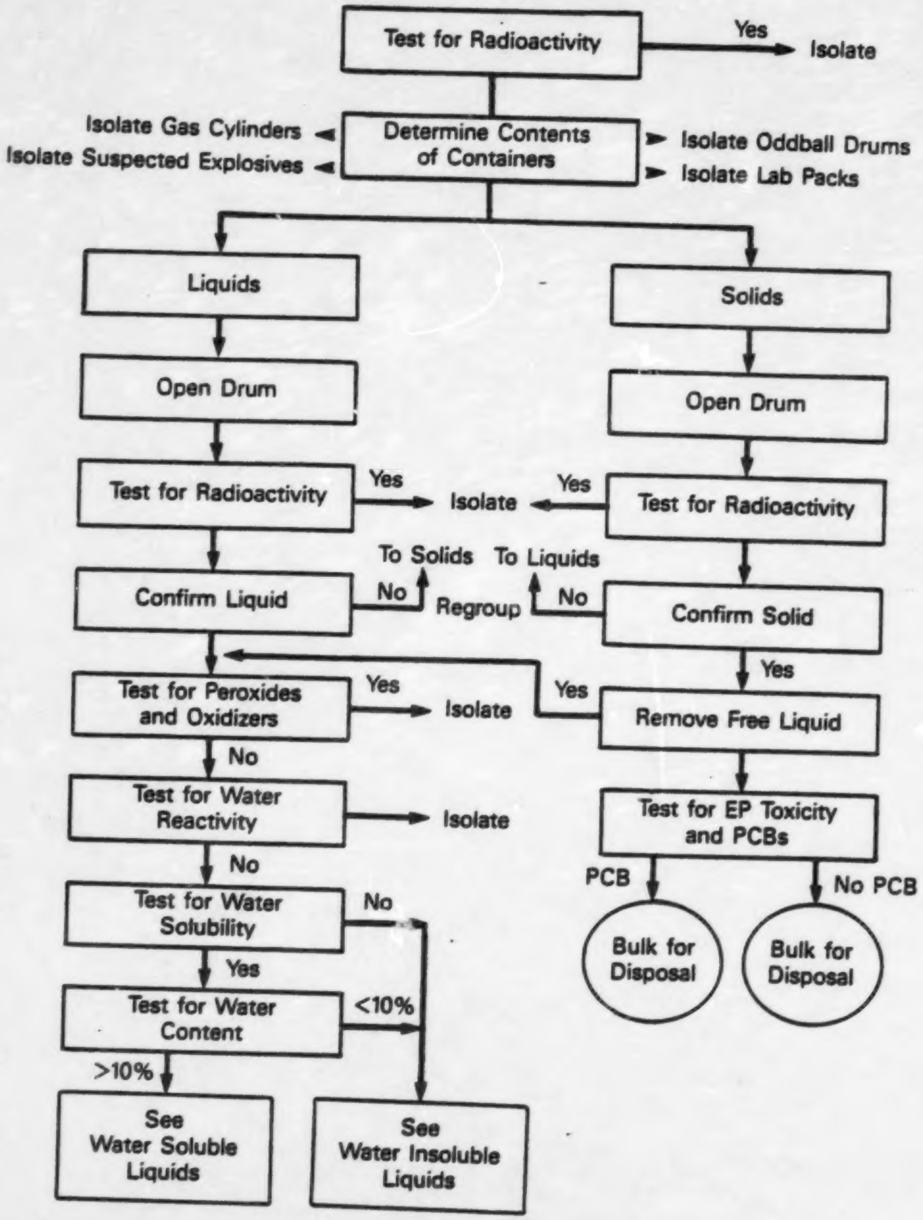
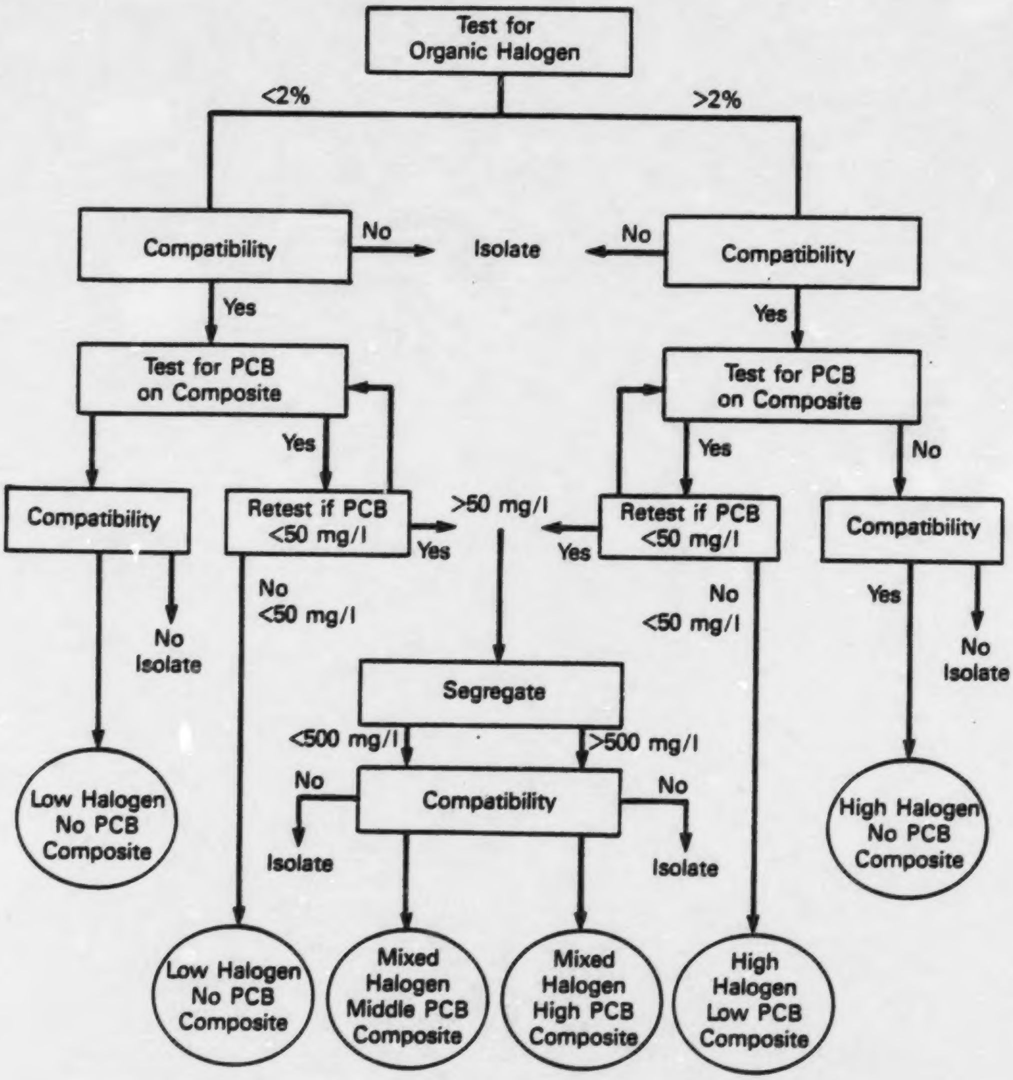

Test for Radioactivity
Yes
Isolate
Isolate Gas Cylinders
Isolate Suspected Explosives
Determine Contents of Containers
Isolate Oddball Drums
Isolate Lab Packs
Liquids
Solids
Open Drum
Open Drum
Test for Radioactivity
Yes
Isolate
Yes
Test for Radioactivity
To Solids
To Liquids
Confirm Liquid
No
Regroup
No
Confirm Solid
Yes
Test for Peroxides and Oxidizers
Yes
Isolate
Yes
Remove Free Liquid
No
Test for Water Reactivity
Isolate
Test for EP Toxicity and PCBs
No
PCB
No PCB
Test for Water Solubility
No
Bulk for Disposal
Bulk for Disposal
Yes
Test for Water Content
<10%
>10%
See Water Soluble Liquids
See Water Insoluble Liquids

Figure 38. Compatibility Testing Protocol (Modified by Princeton Aqua Science)
(Reprinted courtesy of Chemical Manufacturer's Association, Washington, D.C.)


Water Insoluble Liquids Testing

Test for Organic Halogen
<2%
>2%
Compatibility
No
Isolate
No
Compatibility
Yes
Yes
Test for PCB on Composite
Test for PCB on Composite
Yes
Yes
No
Compatibility
Retest if PCB <50 mg/l
>50 mg/l
Retest if PCB <50 mg/l
Compatibility
Yes
Yes
No <50 mg/l
No <50 mg/l
Yes
No Isolate
No Isolate
Segregate
<500 mg/l
>500 mg/l
No
Compatibility
No
Isolate
Isolate
Low Halogen No PCB Composite
High Halogen No PCB Composite
Low Halogen No PCB Composite
Mixed Halogen Middle PCB Composite
Mixed Halogen High PCB Composite
High Halogen Low PCB Composite

Figure 38. (continued) (Modified by Princeton Aqua Science). (Reprinted courtesy of Chemical Manufacturer's Association, Washington, D.C.)

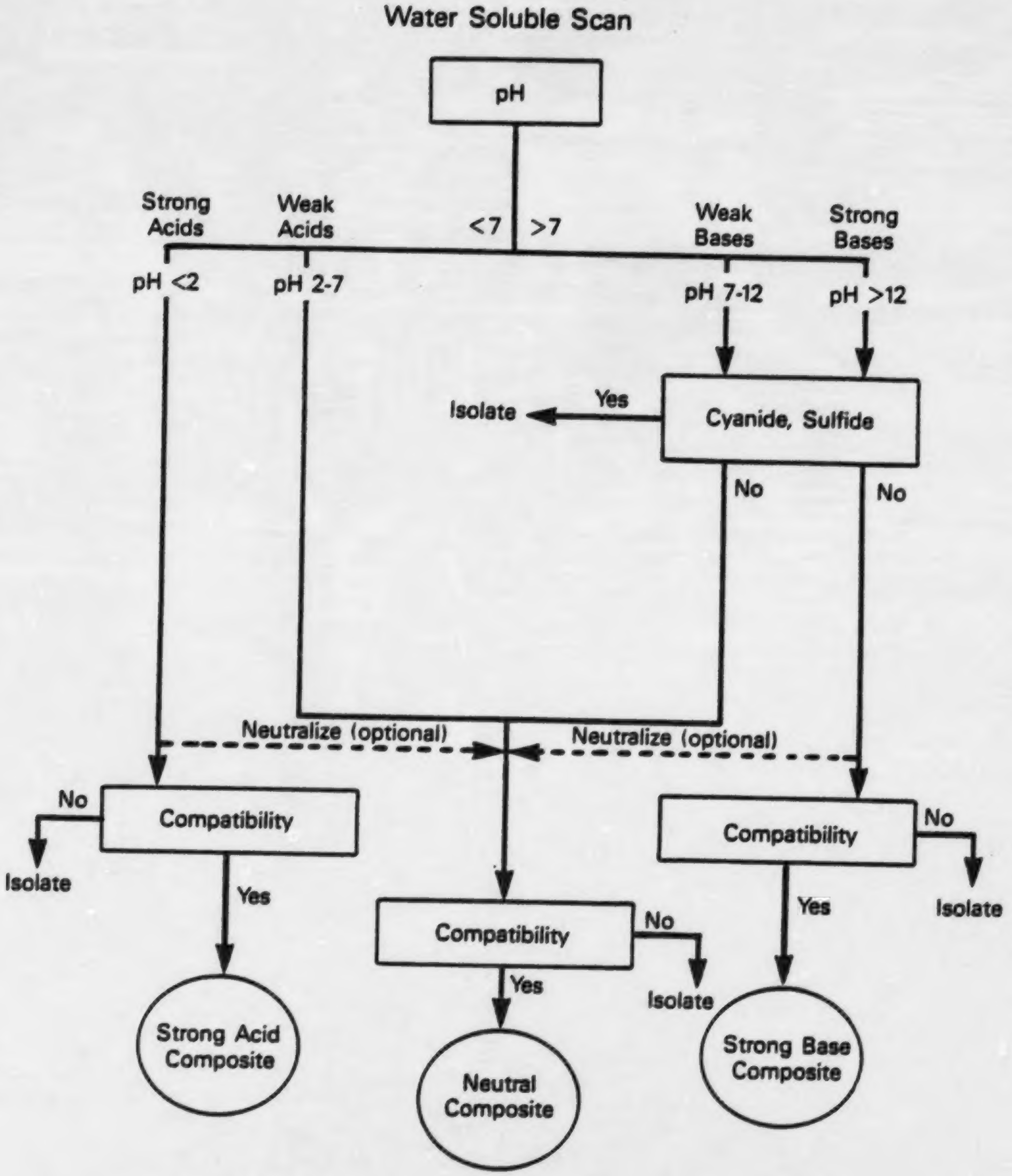

Water Soluble Scan
pH
Strong Acids
Weak Acids
<7
>7
Weak Bases
Strong Bases
pH <2
pH 2-7
pH 7-12
pH >12
Isolate
Yes
Cyanide, Sulfide
No
No
Neutralize (optional)
Neutralize (optional)
No
Compatibility
Isolate
Yes
Compatibility
No
Isolate
Yes
Compatibility
No
Yes
Isolate
Strong Acid Composite
Neutral Composite
Strong Base Composite

Figure 38. (continued) (Modified by Princeton Aqua Science) (Reprinted courtesy of Chemical Manufacturer's Association, Washington, D.C.)

Based on the CMA protocol, wastes can be segregated into the following broad waste categories:

- Liquids
  - Radioactives
  - Peroxides and oxidizing agents
  - Reducing agents
  - Water-reactive compounds
- Water insolubles
  - low halogen, low PCB
  - mixed halogen, high PCB
  - high halogen, low PCB
- Acids
  - strong (pH <2)
  - weak (pH 2-7)
- Bases
  - strong (pH >12), with or without cyanides or sulfides
  - weak (pH 7-12), with or without cyanides or sulfides
- Solids
  - radioactives
  - nonradioactive.

These field compatibility testing procedures are only suitable for determining gross halogen content (> 1%). Samples must be retested for PCBs prior to bulking since the EPA-approved disposal options differ depending on the PCB concentration. Testing to determine gross halogen content is sometimes eliminated if all insoluble wastes are to be incinerated at a facility capable of handling chlorinated organics. However, testing for PCBs is required, regardless of the need for testing other halogenated compounds.

The protocol also requires that a compatibility test be performed by mixing small samples of wastes that are intended to be bulked. Visual observations are made for precipitation, temperature changes or phase separation.

There are some differences between the CMA compatibility protocol and the protocol used by some cleanup contractors. One commonly used procedure is to conduct flammability and ignitability tests on a drum-by-drum basis for both liquid- and solid-containing drums. CMA, on the other hand, recommends that these tests be performed on composite samples before bulking since these tests require more costly and time-consuming analysis (torch test and closed cup flame test, respectively). Another common practice not included in the

CMA protocol is to conduct further testing on samples from drums containing solids. These tests may include water reactivity, water solubility, pH, and the presence of oxidizers. In general, the decision to perform these analyses on a drum-by-drum basis rather than on a composite sample (prior to bulking) is made based on the number of drums and the types of wastes known to be present on site.

Hatayama et al., (1980a) have also provided guidance on waste incompatibilities that can be useful during the waste consolidation process. These researchers have developed a "Hazardous Waste Compatibility Chart" (included in the Appendix) that allows the user to evaluate potential adverse reactions for binary combinations of hazardous wastes. Binary waste combinations are evaluated in terms of the following adverse reactions: heat generation from a chemical reaction, fire, toxic gas generation, flammable gas generation, explosion, violent polymerization, and solubilization of toxic substances.

TESTING COMPOSITE SAMPLES

A detailed analysis of a composite waste is generally required prior to acceptance by a treatment/disposal facility. Once a significant group of compatible waste types (about 100 drums) have been identified, a PCB analysis must be conducted on subgroups (generally about 5 drums). When a composite sample shows a significant PCB concentration (>50 mg/l), each drum in the subgroup must be analyzed separately. Once a compatible group of samples is identified and PCB-contaminated drums are removed, a final disposal analysis is conducted. Muller, Broad, and Leo (1982) have compared the analytical requirements of a number of disposal facilities and found that the tests identified in Table 18 are representative of tests that may be required prior to acceptance of liquids and solids for disposal.

SEGREGATING WASTES BASED ON COMPATIBLE WASTE CLASSES

Once drums have been categorized into compatible waste classes, the drums are assigned a color code that corresponds to their compatibility class (i.e., oxidizers, strong acid, etc.). The drums are then physically segregated on the basis of compatible waste types and consolidation or volume reduction techniques. In this way, compatible waste types can be efficiently combined for final treatment, storage, or disposal. To facilitate easy access to the drums, compatible waste types should be placed in groups of four or in long double rows (CMA, 1982). Spacing between rows or groups should allow easy access to drums by drum handling equipment and rapid exit in case of emergency.

TREATMENT/DISPOSAL OPTIONS

Once the wastes have been categorized, they are assigned appropriate treatment/disposal options. These options are selected based on such factors as protection of public health, regulatory requirements, availability and

TABLE 18. POTENTIAL ANALYTICAL REQUIREMENTS FOR DISPOSAL

1. Flammability
2. pH
3. Specific gravity
4. PCB analysis
5. Thermal content (BTU/lb)
6. Physical state at 70°F
7. Phases (layering in liquids)
8. Solids (%)
9. Hydrocarbon composition
10. Pesticide analysis
11. Sulfur content
12. Phenols
13. Oil and grease (%)
14. Water (%)
15. Viscosity
16. Organochlorine percentage
17. Metals analysis
    - a. Liquids for soluble metals.
    - b. Solids extracted according to the EPA Toxicant Extraction Procedure (24 hr) which shows leachable metals.
    - c. Both liquid and solids checked for concentrations of the following metals:

      Arsenic
      Barium
      Cadmium
      Chromium
      Copper
      Lead
      Mercury
      Nickel
      Selenium
      Silver
      Zinc
18. Both free and total cyanide content checked.
19. Solids checked for solubility in water, sulfuric acid, and dimethyl sulfoxide.

Reprinted from Muller, Broad, and Leo, 1982. Table originally printed in the Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982. Available from Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, MD 20910.

appropriateness of Treatment/Storage/Disposal (TSD) facilities, applicability to site specific conditions (i.e., number of drums, location, etc.), and costs.

Treatment or disposal options for specific waste types are covered in detail in numerous reports, several of which are listed in the references. The U.S. EPA (1981b) prepared a useful summary of major treatment and disposal options for various waste categories. The summary is shown in Table 19. Although this table was prepared specifically for the Pollution Abatement Services Site in Oswego, New York, it is generally applicable for most cleanup operations since it identifies the most widely used treatment or disposal option for various broad waste categories. Nevertheless, the selection of the best treatment/disposal option should be made on a site-specific basis.

The major factors to consider in determining the feasibility and effectiveness of the various treatment options are summarized below:

- Incineration: BTU values, organic chlorine, organic sulfur, water content, viscosity, heavy metals (i.e., percent ash), feasibility of onsite incineration, location of a suitable offsite incinerator

- Aqueous Treatment: pH, acidity, alkalinity, flash point, water content, microbial toxicity, TOC, sulfide, cyanide, metals, feasibility of onsite treatment, sludge disposal if treated onsite, onsite pretreatment requirements

- Resource Recovery:

  - organic solvents and nonemulsified oils: PCB content, halogen content, water content, dissolved metals, and other dissolved compounds, BTU value

  - metals recovery: metal concentration, economics of production of the metal from the raw material

- Secure Landfill: water content, PCB content, radioactivity, reactivity, ignitability, presence of carcinogens, presence of toxics

- Solidification/Stabilization: potential for reversal of reactions, costs, status of technology, compatibility of wastes with a solidifying agent.

Location of suitable facilities for final treatment or disposal depends primarily on the specific waste type. The Hazardous Waste Management Directory (1982-1983) (Pennsylvania Environmental Research Foundation, Inc.) identifies treatment/disposal facilities by city and state. The types of wastes handled, the treatment/disposal processes used, and the service are listed for each facility. For radioactive- and PCB-containing wastes (except liquids with <50 ppm PCB) the options are rather limited. Figure 39 shows

TABLE 19. MAJOR TREATMENT/DISPOSAL ALTERNATIVES FOR VARIOUS WASTE TYPES

Waste Segregation	Waste Type	Aqueous Treatment	Recovery/ Recycle[a]	Incineration	Solidification Fixation/ Dewatering	Secure Land Burial
Radioactive	Solid				P	LD
	Liquid				P	LD
Water Reactive	Liquid	U				
	Solid (alkaline metals)	PS		U		
Strong Reducer	Solid/ Liquid	U				
Strong Oxidizer	Solid/ Liquid	U				
Organic Liquid with Low Halogen Concentration (<2% halides, <50 ppm PCB)	Solvents		PS/U	U		
	Oil		PS/U	U		
	Other		PS/U	U		
Organic Liquid with High Halogen Concentration (>2% halides, <50 ppm PCB)	Solvents		PS/U	U		
	Oil			U		
	Pesticides, Herbicides			U		
	Other		PS/U	U		

(continued)

TABLE 19. (continued)

Waste Segregation	Waste Type	Aqueous Treatment	Recovery/ Recycle[a]	Incin- eration	Solidification/ Fixation/ Dewatering	Secure Land Burial
Aqueous Acid	Acids with or without heavy metals	PS/U			P*	LD*
	Organic Acids	PS/U*		U*	P*	LD*
Aqueous Base Contaminated With Cyanide	——	U				
Aqueous Base Contaminated With Sulfide	——	U				
Aqueous Base	Alkalines pH 7-12 with or without heavy metals	PS/U			P*	LD*
	Organic Alkalines	PS/U		U*	P*	LD*
Solid Material Uncontaminated w/PCB (<50 ppm)	Inorganic Acid Sludge				P**	LD
	Inorganic Alkaline Sludge				P**	LD

(continued)

TABLE 19. (continued)

Waste Segregation	Waste Type	Aqueous Treatment	Recovery/ Recycle[a]	Incin- eration	Solidification/ Fixation/ Dewatering	Secure Land Burial
Solid Material Uncontaminated w/PCB (<50 ppm) (continued)	Organic Acid Sludge			U*	P	LD
	Organic Alkaline Sludge			U*	P	LD
	Salts/ pure organic			U	P	LD
	Tar/ Residues (i.e., still bottoms filter cake, spent catalyst, etc)			U	P	LD
	Other Organic Sludges			U	P	
	Metals		PS		P	LD
	Asbestos			P	U	
PCB Contaminated Material	50-500 ppm	PS		U	P	LD
	>500 ppm	PS		U		

U.S. EPA, 1981b

Key

U = Ultimate Disposal
PS = Pretreatment Sidestream
P = Pretreatment
LD = Land Disposal
* = Solid Phase Only
** = Neutralization Part of Process
[a] = Recovery/recycle includes fuel blending, auxillary fuels and product recovery

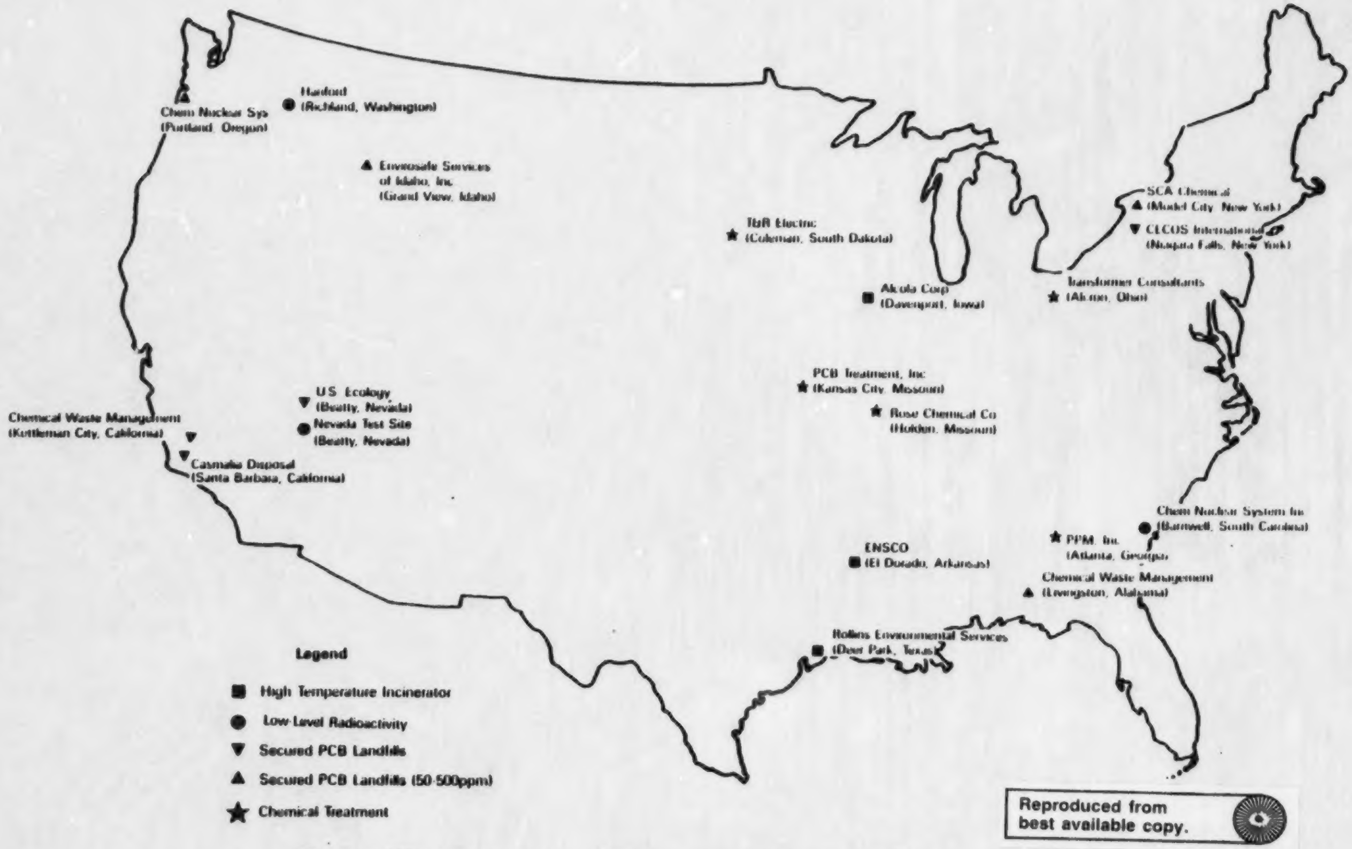

Chem Nuclear Sys (Portland, Oregon)
Hanford (Richland, Washington)
Envirosafe Services of Idaho, Inc. (Grand View, Idaho)
U.S. Ecology (Beatty, Nevada)
Nevada Test Site (Beatty, Nevada)
Chemical Waste Management (Kettleman City, California)
Casmalia Disposal (Santa Barbara, California)
T&R Electric (Coleman, South Dakota)
Alcola Corp (Davenport, Iowa)
PCB Treatment, Inc (Kansas City, Missouri)
Rose Chemical Co (Holden, Missouri)
ENSCO (El Dorado, Arkansas)
Rollins Environmental Services (Deer Park, Texas)
SCA Chemical (Model City, New York)
CECOS International (Niagara Falls, New York)
Transformer Consultants (Akron, Ohio)
Chem Nuclear System Inc (Barnwell, South Carolina)
PPM, Inc. (Atlanta, Georgia)
Chemical Waste Management (Livingston, Alabama)
Legend
■ High Temperature Incinerator
● Low-Level Radioactivity
▼ Secured PCB Landfills
▲ Secured PCB Landfills (50-500ppm)
★ Chemical Treatment

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Figure 39. Locations of Treatment/Disposal Facilities for PCBs or Radioactive Wastes

(Sources: USEPA, 1983b; USEPA, 1983c; USEPA, 1983d)

Note: Mobile incinerators, mobile treatment system, and permitted boilers are not included. Permitted chemical treatment facilities may not accept outside wastes.

the location of facilities capable of secure landfilling of low-level radioactive wastes and PCB containing wastes and of high temperature incineration of PCB liquid wastes in excess of 500 ppm. The facilities capable of handling low-level radioactive wastes have very specific requirements regarding types, concentrations, and packaging of radioactive materials. Requirements for the land disposal of low-level radioactive wastes are outlined in the Low-Level Radioactive Wastes Policy Act of 1980 and 10 CFR Parts 10, 19-21, 30, 40, 51, 61, 70, 73, and 170. Requirements for treatment and disposal of PCB-containing wastes are outlined in 40 CFR Part 761. The PCB requirements are summarized briefly in Figure 40.

PREPARATION OF LIQUID WASTES FOR FINAL TREATMENT OR DISPOSAL

Once the final treatment or disposal options have been determined, the wastes are then prepared to meet the requirements of the treatment or disposal facility and the transportation regulations. In some instances this involves pretreatment of the wastes. In other cases, compatible wastes are simply bulked for transport or transferred into a DOT-approved container or fiber container in the case of onsite incineration.

Onsite Pretreatment

Onsite pretreatment of wastes may be required to make them acceptable for offsite transport, to meet the requirements of the treatment facility, or to allow them to be bulked with other similar wastes. Onsite pretreatment is generally limited to the following:

- Acid-base neutralization
- Metal precipitation
- Hypochlorite oxidization of cyanide and sulfide
- Flash point reduction (use of a Freon-based flash suppressant).

Chemical reactions should be carried out under carefully controlled conditions using a "compatibility chamber" or reaction tank for mixing wastes. O.H. Materials, Findlay, Ohio (undated), developed a 38,000 liter (10,000 gallon) "compatibility chamber" that monitors the heat of reaction using thermocouples mounted in the chamber. A nonsparking bar scraper with explosion-proof drive, prevents sludges and solids from entering the collection chamber. Other cleanup contractors use small storage tanks. If opened, the tank should have a minimum of 2 feet of freeboard or some sort of containment structure equal to the volume of 2 feet of freeboard. Ideally, the storage tanks should have some type of closure and should be painted black to control loss of volatiles. Drums should be emptied into an open chamber or tank using the grappler. This provides for a safe and rapid means of bulking wastes (Figure 41). Hydraulic drum dumpers (Section 7, Figure 20) are also suitable for dumping the contents of drums into a reaction tank.

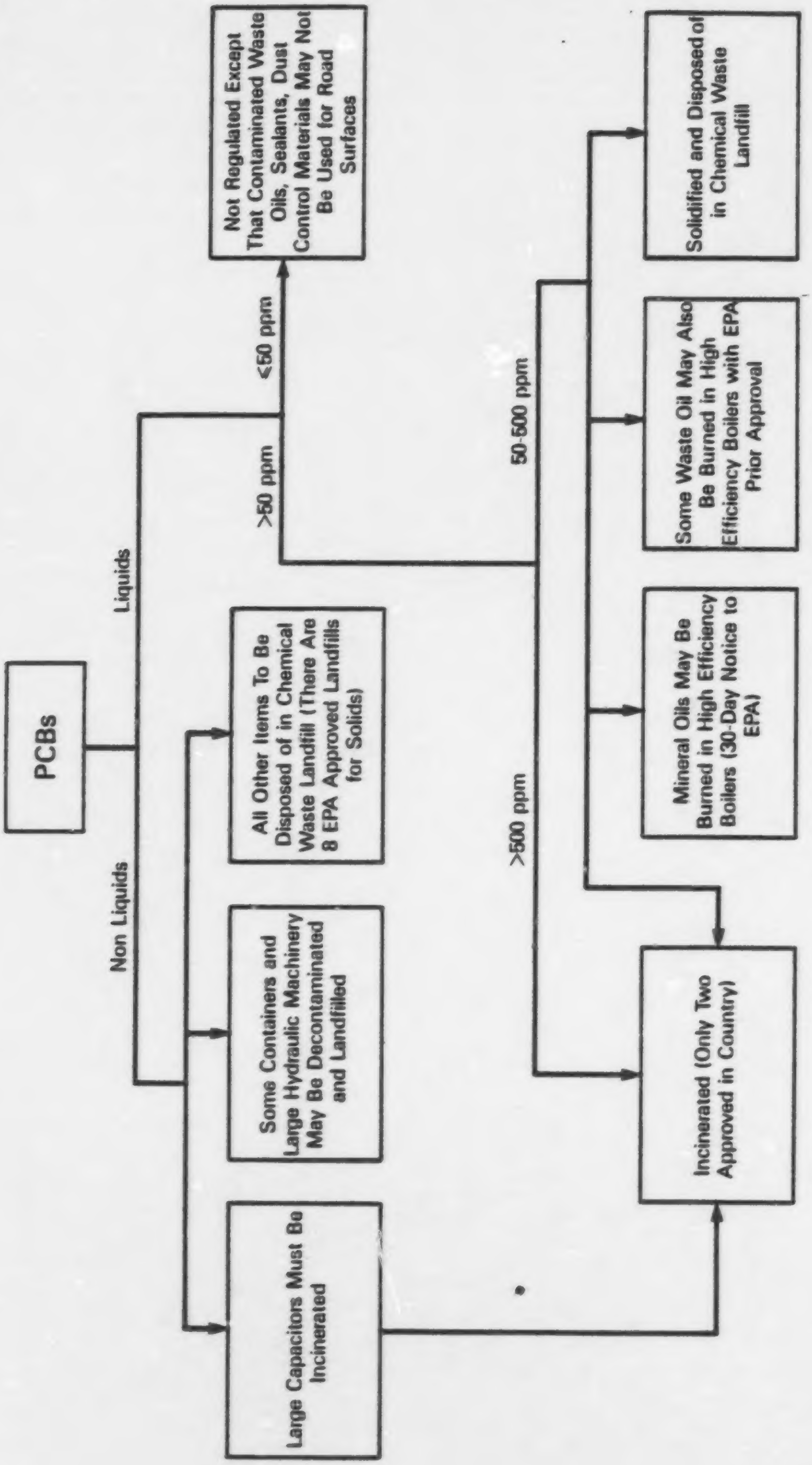
PCBs
Non Liquids
Liquids
Large Capacitors Must Be Incinerated
Some Containers and Large Hydraulic Machinery May Be Decontaminated and Landfilled
All Other Items To Be Disposed of in Chemical Waste Landfill (There Are 8 EPA Approved Landfills for Solids)
>50 ppm
<50 ppm
Not Regulated Except That Contaminated Waste Oils, Sealants, Dust Control Materials May Not Be Used for Road Surfaces
>500 ppm
50-500 ppm
Incinerated (Only Two Approved in Country)
Mineral Oils May Be Burned in High Efficiency Boilers (30-Day Notice to EPA)
Some Waste Oil May Also Be Burned in High Efficiency Boilers with EPA Prior Approval
Solidified and Disposed of in Chemical Waste Landfill

Figure 40. Federal PCB Disposal Regulations

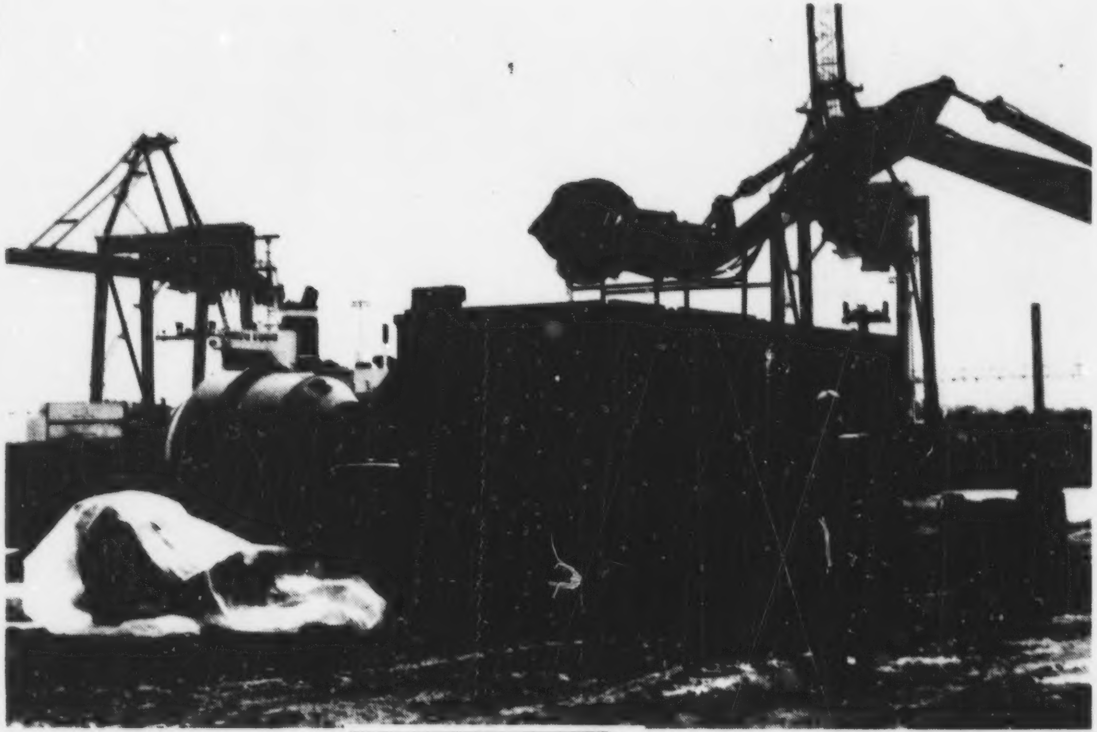

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Figure 41. Use of Grappler Arm and Compatibility Chamber for Combining Compatible Wastes

(Courtesy of O.H. Materials Co., Findlay, OH)

Consolidation

In instances where the contents of a large number of drums can be consolidated for purposes of treatment or disposal, vacuum equipment can offer a highly efficient approach to consolidation.

Vacuum trucks are available in capacities ranging from about 4,700 to 23,000 liters (1,250-6,000 gallons.) They are available in a range of vacuum strengths and with a wide variety of options. Figure 42 illustrates a number of available options for one manufacturer's line of equipment (Huber Manufacturing Inc., undated).

Portable skid-mounted vacuum units are also available. They can be airlifted, dragged by bulldozer, or even hauled on the back of a pickup truck to otherwise inaccessible areas. These units are generally available in capacities ranging from 1,900 to 5,700 liters (500-1,500 gallons), although units that can handle up to 11,400 liters (3,000 gallons) are manufactured. Skid-mounted units with vapor recovery systems are also available.

A number of factors should be considered prior to contracting for the services of a vacuum truck. Because of the large capacity of the vacuum cylinder, vacuum trucks are generally not well suited to sites with fewer than 30 drums to be consolidated. For a small site it is generally more cost-effective to overpack the drums or to use a vacuum skid-mounted unit. This is due to the high transportation costs and cost of handling wastewater generated from decontaminating the truck. The water or solvent used in decontamination is considered hazardous and must be disposed of or treated as such. Highly hazardous chemicals such as PCBs require stringent decontamination procedures in accordance with the Toxic Substances Control Act (TSCA).

The cost of decontamination can be substantially reduced by a number of good management practices. The vacuum truck or skid-mounted unit should be dedicated as much as possible to handling a certain type of waste so that decontamination is not required between each load. The units should also be sized for the job so that excessive decontamination water is not generated as a result of choosing an oversized vacuum cylinder.

Another important factor to consider in selecting vacuum trucks or skid-mounted units is the compatibility of wastes with materials of construction. Vacuum cylinders can be purchased in carbon steel, stainless steel, aluminum, nickel, etc., and/or with a variety of coatings including epoxy, fiberglass, and neoprene rubber. In addition to selecting vacuum trucks with compatible liners, compatibility problems can be minimized by allowing wastes to react in a "reaction tank" or "compatibility chamber" where the heat of reaction can be released before pumping the wastes into the vacuum truck.

In addition, when a grappler is available, it is often more efficient to dump the contents of the drums into a chamber or tank and transfer the load to the vacuum truck rather than to load each drum separately into the vacuum truck.

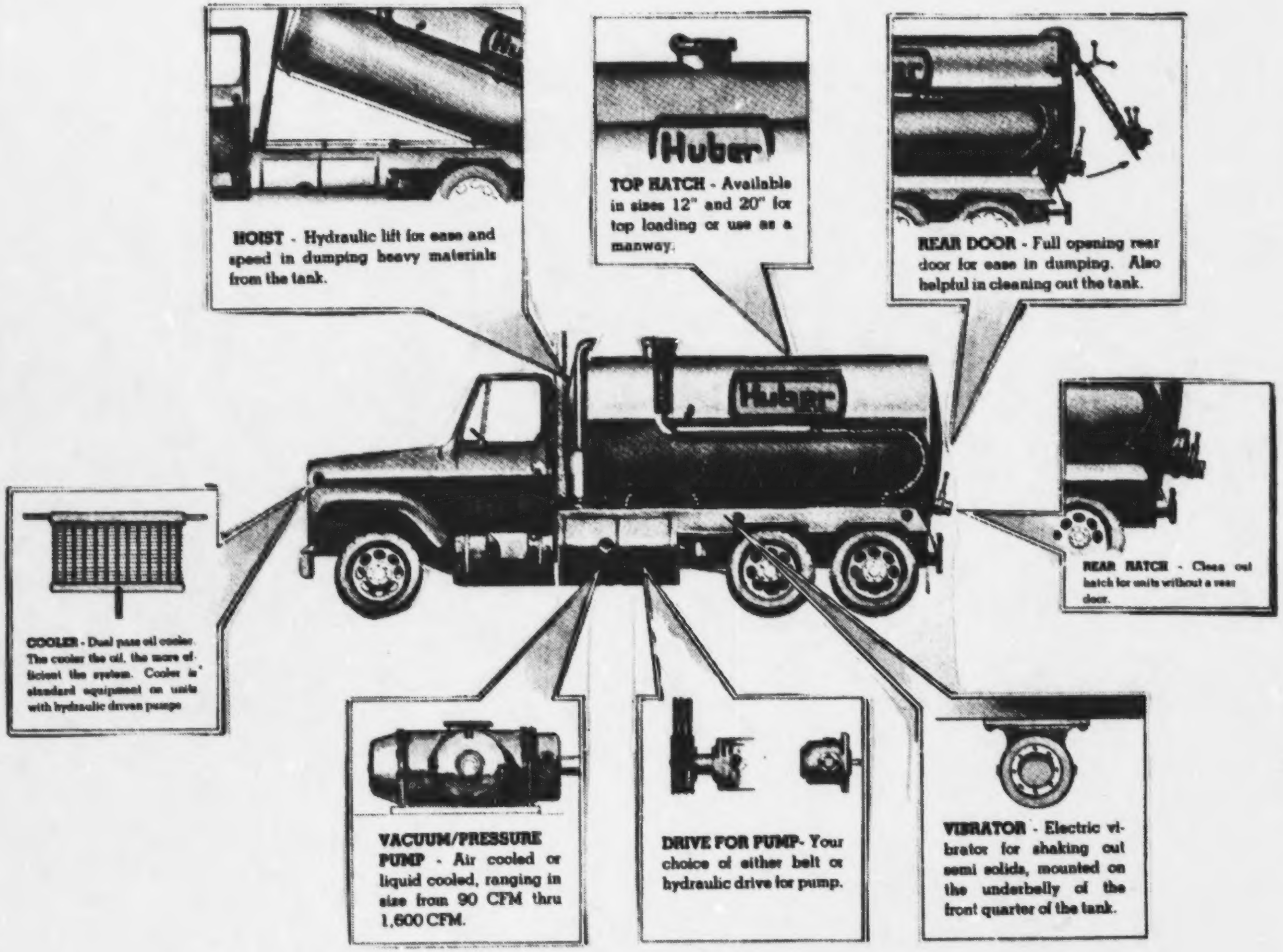
HOIST - Hydraulic lift for ease and speed in dumping heavy materials from the tank.
Huber
TOP HATCH - Available in sizes 12" and 20" for top loading or use as a manway.
REAR DOOR - Full opening rear door for ease in dumping. Also helpful in cleaning out the tank.
Huber
COOLER - Dual pass oil cooler. The cooler the oil, the more efficient the system. Cooler is standard equipment on units with hydraulic driven pumps
REAR HATCH - Clean out hatch for units without a rear door.
VACUUM/PRESSURE PUMP - Air cooled or liquid cooled, ranging in size from 90 CFM thru 1,600 CFM.
DRIVE FOR PUMP- Your choice of either belt or hydraulic drive for pump.
VIBRATOR - Electric vibrator for shaking out semi solids, mounted on the underbelly of the front quarter of the tank.

Figure 42. Available Options for Streamline Vacuum Trucks

(Courtesy of Streamline Manufacturing, Gulfport, MS)

Use of Overpacks and Drums

Under certain circumstances it is more economical or acceptable to transport liquid wastes in drums or overpacks rather than to bulk them. This is the case when the number of drums containing compatible waste types is too few to make the use of vacuum equipment economical or when there are a few drums that contain highly toxic or incompatible wastes that cannot be bulked with other wastes without contaminating the load.

Procedures for overpacking or transferring liquids to new drums were discussed in Section 7. Drums or overpacks must meet with DOT specifications with regard to waste-container compatibility, packaging, and labeling before being transported offsite. Specifications are found in 49 CFR 172 through 179. If wastes are to be incinerated, fiber drums should be considered as an alternative to steel drums. Fiber drums generally can meet DOT requirements by lining or overpacking them (Gordon, 1982). The use of a fiber drum rather than a steel drum greatly simplifies the incineration process.

In instances where the contents of several partially filled drums are to be combined, a simple flow gauge can be used to monitor the liquid level in the drums to prevent overfilling. These gauges fit into standard bungs and can be easily adjusted to any desired liquid level (Industrial Safety and Material Handling, 1981; BASCO, 1982).

PREPARATION OF SOLID WASTES AND SOILS FOR FINAL TREATMENT OR DISPOSAL

Secure landfilling is the most common means for ultimate disposal of solid wastes including sludges, process residues, still bottoms, and highly contaminated soils. RCRA, State, and DOT regulations will dictate the type of pretreatment required to make the waste acceptable for secure landfilling. Soils and wastes may be bulked, transferred to a new drum, or overpacked depending upon specific waste and site conditions and requirements of the secure landfill. Incineration can be a viable alternative to landfilling some solids provided water content and heavy metal concentrations are low. Solidification/stabilization methods are also a potential treatment option, but their use is limited to highly toxic materials because of the high cost of solidification.

Use of Drums and Overpacks

In many instances, drums containing sludges and solids are overpacked or their contents are transferred to new or reconditioned drums. Highly contaminated soils are sometimes drummed as well if the volume is small.

RCRA land disposal regulations require that all free-standing liquid be removed by decanting or by mixing with sorbents before landfilling. No visible pools or layers of liquid are permitted (Federal Register, March 22, 1982). One common practice is to mix contaminated soils with the drummed waste to absorb the free liquid. Other absorbents commonly used include cement kiln dust, fly ash, fuller's earth, saw dust, and vermiculite. A number of other stabilization/solidification processes are available including encapsulation, cement-based processes, thermoplastic processes, organic polymer techniques, and lime-based processes. Success with these methods is highly waste specific. The cement-based and lime-based processes that use relatively cheap and readily available materials have more practical applications than other solidification/stabilization methods. Cement- and lime-based solidification may be used to solidify inorganic sludges, although the tendency at hazardous waste sites is to use absorbents such as saw dust, fuller's earth, etc., rather than the more time-consuming solidification processes.

Consolidation

Large volumes of contaminated soils and solid wastes are generally prepared for transport by combining compatible wastes and loading them in a box trailer. As indicated in Section 7, highly contaminated soils and spilled waste materials that are excavated during the drum removal operation either are transferred to a diked and lined storage area or vacuumed as encountered using high-strength industrial vacuum loaders ("Vactor" or "Supersucker"). Compatible solids and sludges in drums may be combined with these highly contaminated soils to provide a more economical method of packaging and transporting solid wastes. Sludges and solids may be mixed directly with the highly contaminated soils along with absorbent material to create a stable waste pile that is free of visible liquids. These wastes can then be transferred to a box trailer truck, Vactor or Supersucker. In instances where the sludges and solids are to be transferred from drums to a Vactor or Supersucker, the wastes should first be dumped into a compatibility chamber to avoid reactions that could damage the vacuum system's storage box. Where box trailers are being used, they should be lined and covered with a layer of sorbent material. The soils and solids can be rapidly transferred into the box trailer using a backhoe or a front-end loader (Figure 43).

Handling Nonhazardous Soils

Soils that are determined by laboratory analysis to be nonhazardous are generally not landfilled but treated or left onsite. There are several alternatives available for handling slightly contaminated soils depending on the type of wastes, the volume of soils, and the site location. These include:

- Backfilling excavation trenches if contaminant levels are very low
- Aerating the soils using a rototiller to release organic vapors
- Employing microbial degradation using indigenous or adapted microorganisms with or without addition of nutrients and air
- Using chemical treatment methods such as neutralization, redox reactions, or precipitation.

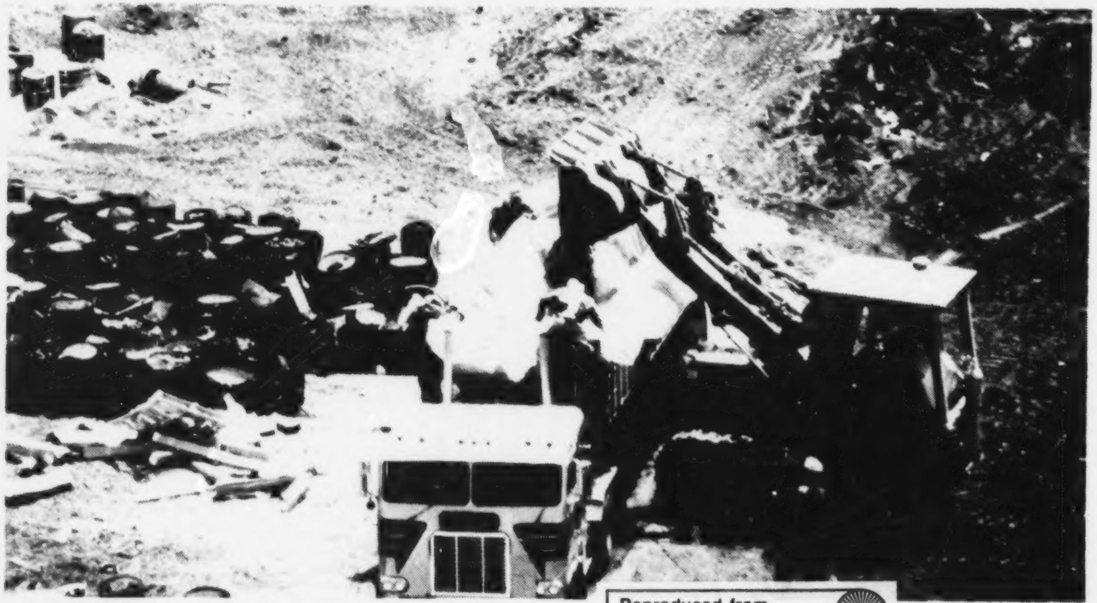

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Figure 43. Combined Handling of Sludges and Contaminated Soils at the Chemical Control Site

(Courtesy of O.H. Materials Co., Findlay, OH)

GAS CYLINDERS

Once compressed gases are identified by sampling, they can be disposed of by one of several methods. However, extreme care must be taken in choosing the appropriate treatment alternative and in handling the gases. If possible, the gas supplier should be contacted for appropriate handling techniques. Physical, chemical, and toxicological data for specific gases should be consulted prior to selecting the appropriate treatment method. Safe handling procedures should be followed at all times. The cylinders should never be dragged even for short distances or permitted to strike each other. Protective caps should be kept over the valves at all times (Matheson Gas Products, undated).

Gas cylinders can be disposed of using the appropriate method discussed below (Matheson Gas Products, undated):

- Return to the manufacturer or supplier if known

- Vent confirmed nontoxic gases - cylinders containing inert gases such as helium, argon, or nitrogen do not represent a hazard unless they are situated in a confined place with no ventilation. The cylinders should be moved to a well-ventilated outside area, and the gases should be discharged or vented at a moderate rate. After the gas has been discharged the valve should be closed.

- Chemical treatment - Some alkaline and acidic gases may be chemically treated but should be done so with extreme caution since these gases are corrosive and toxic. Alkaline gases are flammable, as well.

  Alkaline gases such as ammonia and the lower alkyl amines should be handled as follows: the cylinders should be moved to an isolated area free of all sources of ignition. A control valve equipped with a trap or check valve should be attached to the cylinder and a long piece of flexible hose should be connected to the control valve outlet. The gas should then be discharged at a moderate rate into an adequate amount of sulfuric acid solution. When the cylinder is empty, the control valve should be closed and the resultant solution treated and disposed.

  Acidic gases are handled similarly. However, the gases should be discharged into an adequate amount of about 15 percent aqueous sodium hydroxide.

- Destructive combustion - The best procedure for disposing of flammable gases is controlled burning in an isolated area.

LAB PACKS

The first step in handling lab packs is to manually separate the individual bottles in the drums into categories of knowns, unknowns, and debris. This is accomplished by observing labels, physical appearances, and general chemistry (i.e., pH, corrosivity, reactivity, explosiveness) of contents, and by determining the origin of the lab pack itself. Care should be taken to preserve any labels or partial labels present.

Known materials are handled by segregating them into compatible groups. The chemically compatible bottles can either be repacked in conformance with appropriate U.S. EPA, and DOT regulations regarding shipment, or they can be bulked for treatment or disposal.

Unknowns should be stored separately from known materials. If possible, the generator of the lab packs should be contacted to assist in material identification. Containers that are unknown should be separated into similar groups based on such characteristics as physical state, color, particle size, etc. A shock test should be performed on samples from each group to determine whether it is safe to open the containers within tha group. After the shock test, the remaining containers should be opened, checked for visual similarity, and randomly sampled for compatibility testing.

Explosive fractions of lab packs must be handled with extreme care and require the presence of an expert in explosives. However, when there is reason to believe such chemicals are present, extreme care is necessary during staging and characterization activities. Aside from the shock test, one indication of the presence of explosive or shock-sensitive compounds is the formation of crystals around the caps or within individual bottles.

Any explosive material that is identified should first be labeled and placed within a remote bunker or staging area in a vermiculite filled container until all of the waste is categorized. The location of a staging area for explosive wastes should be based upon a careful evaluation of the quantity of explosives and their relative hazard. The staging area should be enclosed with a fence or dike to minimize the adverse effects of any premature detonation.

The treatment of explosive or shock-sensitive wastes differs from that of other categories of hazardous wastes. Typically, these types of wastes are either detonated or incinerated under very controlled conditions. Detonation at a specially designated site or uncontrolled waste site, if sufficiently remote, is a widely accepted practice for disposal of explosives.

Once a sufficient quantity of explosive material has been categorized and a remote site has been located for detonation, the State Fire Marshall should be contacted to detonate the wastes. For the removal and disposal of explosive waste, one basic permit is required from the U.S. Bureau of Alcohol, Tobacco, and Firearms. The permit requirement is associated with the actual transport of explosives and the purchase of any explosive materials required to detonate the waste material. Once the Federal permit is secured, written approval from the State and local governments is required before detonation is begun.

Typically, a bomb trailer would be employed to transport the wastes to the site. Wastes would be segregated according to their chemical compatibility and shock sensitivity. For example, very shock-sensitive material such as blasting caps and nitroglycerin would not be transported with nonshock-sensitive materials possessing explosive properties. This would ensure that premature detonation of a shock-sensitive item would not result in a detonation of more stable explosives.

Detonation should be accomplished by exploding downward into clean, moist earth. At the Picillo Farms site, the detonation area was to be triple lined with at least 2 feet of soil between each layer of 6 mil polyethylene plastic film (Perkins Jordan, Inc., 1982). The debris remaining after the explosion should be cleaned up before the next explosion is prepared.

DRUM CRUSHING

There are several options available for handling empty drums. Generally, as the empty drums are excavated or generated during consolidation they are transferred into a dump truck and hauled to a drum crushing area. Depending upon the site and hazard of the wastes which were stored in the drums, the empty drums may be crushed daily to minimize the release of volatile compounds or they may be stored temporarily. If the empty drums are temporarily stored, measures should be taken to prevent the accumulation of precipitation in the drums and leaching of residues into the ground. These measures might include: diking the empty drum staging area, lining it with plastic, clay, or sorbent material and covering the empty drums with a liner material.

Before crushing, the drums should be checked for liquid and solid residue. Drums containing more than 5 centimeters (2 inches) of residue should not be considered empty. Liquid residue should be transferred to a compatibility chamber or reaction tank. Solid residue should be shoveled or scrapped out and transferred to a bulk storage trailer.

Use of a portable hydraulic drum crusher is generally the most efficient method for crushing large numbers of drums. Drums can be crushed to a thickness of 20 centimeters (8 inches) or less. In instances where the residues are highly toxic or difficult to remove, a drum shredder can be used. O.H. Materials has a shredder that uses negative air pressure to prevent escape of vapors (personal communication with R. Graziano and S. Insalaco, O.H. Materials, Findlay, Ohio, 1982). If the number of empty drums onsite is few, a backhoe or front-end loader can be used for crushing.

Generally, crushed drums are disposed of in bulk storage trailers without segregating them into the compatibility class of the waste that they contained. However, some disposal facilities do require that they be segregated into compatible waste categories. If there are very few empty drums onsite, it may be cost-effective to overpack them and haul them with drums to disposal.

DECONTAMINATION

All equipment, facilities, and field personnel must be decontaminated before entering the clean zone. Procedures for personnel decontamination are detailed in several of the references on waste site safety procedures listed in Section 3 and will not be discussed here.

The equipment decontamination area should preferably include a hard surface pad (concrete or asphalt) that is diked or bermed to collect rinse water and a collection sump from which the contaminated water can be collected and treated. Where the site is highly degraded and further remedial actions are anticipated, all of the precautions may not be required.

Equipment decontamination may include degreasing if required, followed by high-pressure hot water rinsing with low volume nozzles, supplemented by detergents and solvents, as needed (U.S. EPA, 1982c). In winter it may be necessary to add alcohol to water to prevent freezing. In order to reduce the volume of rinse water generated, brushes and scrapers may be initially used to remove packed or caked contaminated soils. Special attention should be given to material on and within the tracks and sprockets of crawler equipment, and tires and axles of trucks and rubber-mounted equipment (U.S. EPA, 1981b). Any small tools or personnel safety equipment that cannot be decontaminated should be overpacked and disposed of in a secure landfill.

Decontamination of temporary facilities erected onsite for the cleanup operation is generally limited to low-volume, high-pressure, hot water rinsing. More rigorous decontamination procedures may be required for warehouses or trailers if drums were stored in them.

SECTION 10

INTERIM STORAGE AND TRANSPORTATION

STORAGE

Regulations Affecting Interim Storage Facilities

Drum handling operations at hazardous waste sites frequently involve the temporary storage of drums onsite. Conditions may require that the drums be stored for an undetermined period of time until additional funds become available to transport them offsite or until a suitable site is located for their final disposal. In the event that drums may be stored longer than 90 days, the storage area(s) should comply with the intent of RCRA promulgated standards (40 CFR, Part 264) for waste storage at RCRA permitted facilities (treatment, storage, and disposal facilities). Where onsite storage is expected to occur for only a short duration, measures should nevertheless be taken to provide some means of secondary containment and segregation of incompatible wastes.

In many instances the waste site is located in a confined or congested area and it is not possible to meet the RCRA requirements for spacing and layout. For these cases, the state or on scene coordinator (OSC) may have to make alternate provisions to minimize releases and maximize safety during storage. The discussion below focuses on RCRA requirements for storage of hazardous wastes. Less stringent storage requirements are generally satisfactory for short-term storage.

Selection and Layout of the Temporary Storage Area

RCRA requires that incompatible waste types be separated by dikes, berms, walls, or other devices and that the entire storage area be secured by fencing. RCRA also requires that ignitable or reactive wastes be a minimum of 15 meters (50 feet) from the site property line and separated from any source that may cause them to ignite or react. Although not specifically mentioned by RCRA, special precautions may be required for specific waste types. For instance, gas cylinders and explosives, if stored in the open, should be assigned to separate storage areas that are kept cool, dry, and protected from sunlight and temperature extremes. Adequate aisle space should be maintained to allow the unobstructed movement of personnel, fire protection equipment, etc., in the event of an emergency (40 CFR, Part 264). The aisle space should also be adequate to carry out inspections and allow adequate mobility for forklift trucks or other vehicles used in loading drums for offsite transport. These spacing requirements generally result in a layout in which the drums are placed in long double rows or in groups of four with adequate spacing between each row or group.

When the waste site is located in a large unconfined area, it may be possible to be more discriminating about the location of the temporary storage area. The geohydrology of the site should be studied to determine where there are low permeability soils in an elevated ground area suitable for the storage site. This is particularly important in an area with a high water table.

Waste Containment Procedures

RCRA regulations require that a permanent container storage area have a containment system capable of holding spills, leaks, and precipitation. To comply with this intent, there are several measures which must be taken. Generally, these measures would provide reasonable assurance of waste containment at a hazardous waste site without adding excessively to the cleanup costs.

The interim storage area should have a base underlying the containers that is free of cracks and gaps and is sufficiently impermeable to contain leaks, spills, and accumulated rainfall until the material can be detected and removed. The storage area may be underlain by low permeability, compacted clay; plastic liner material; or asphalt or concrete pads, provided the material is compatible with the wastes. Table 20 summarizes the compatibility of various liner materials with several broad waste classes. If the chemicals can be neutralized, an alternative would be to cover the base of the storage area with crushed limestone, shells, or other neutralizing materials. The disadvantage of such neutralizing ground cover is that it must be removed and replaced promptly in the event of a spill.

An interim storage area should have sufficient capacity to contain 10 percent of the volume of the containers or the volume of the largest container, whichever is greater. Run-on should be prevented unless the system has sufficient excess capacity to contain it (CFR 40, Part 264). This is generally accomplished by constructing a system of dikes or berms around the perimeter of the storage area as well as between areas containing incompatible wastes. Dikes and berms may be constructed of well compacted soils, cinder blocks, or concrete. Earthen dikes are ideally constructed of erosion-resistant, low-permeability compacted clays, although, in practice, readily available soils and excavation equipment are often used at waste sites. Table 21 lists different soil types and ranks them based on percolation control and resistance to wind erosion. Clay, silty clays, and silt are most suitable for dike construction. The problem with using improper earth materials for constructing dikes and berms is exemplified by a problem that occurred at the Seymour Site in Indiana. Originally, a sand dike was built at a storage area on the site at a cost of $800,000. The dike washed away in a heavy rainfall and had to be replaced by a clay dike (Hazardous Waste Report, 1981). Earthen dikes constructed of less suitable materials can be stabilized by mixing the soil with bentonite or fly ash and lime or by coating the surface of the dike with an asphaltic emulsion.

TABLE 20. LINER-INDUSTRIAL WASTE COMPATIBILITIES

Liner Material	Caustic Petroleum Sludge	Acidic Steel-Pickling Waste	Electroplating Sludge	Toxic Pesticide Formulations	Oil Refinery Sludge	Toxic Pharmaceutical Waste	Rubber and Plastic
Soils:							
Compacted clayey soils	P	P	P	G	G	G	G
Soil-bentonite	P	P	P	G	G	G	G
Admixes:							
Asphalt-concrete	F	F	F	F	P	F	G
Asphalt-membrane	F	F	F	F	P	F	G
Soil asphalt	F	P	P	F	P	F	G
Soil cement	F	P	P	G	G	G	G
Polymeric membranes:							
Butyl rubber	G	G	G	F	P	F	G
Chlorinated polyethylene	G	F	F	F	P	F	G
Chlorosulfonated polyethylene	G	G	G	F	P	F	G
Ethylene propylene rubber	G	G	G	F	P	F	G
Polyethylene (low density)	G	F	F	G	F	G	G
Polyvinyl chloride	G	F	F	G	G	G	G

G = Good, F = Fair, P = Poor.
Source: Stewart, 1978.

TABLE 21. RANKING OF SOIL TYPES BASED ON PERCOLATION CONTROL AND RESISTANCE TO WIND EROSION

	Ranking for	
Soil Type	Impeding Percolation	Resistance to Wind Erosion[1]
Gravel	10	1
Silty Gravel	7	3
Clayey Gravel	5	5
Sand	9	2
Silty Sand	8	4
Clayey Sand	6	6
Silt	4	7
Silty Clay	2	8
Clayey Silt	3	9
Clay	1	10

[1] Assuming low soil moisture and no cover vegetation.

Source: Lutton, 1979.

RCRA standards also require that storage areas be designed for sufficient drainage so that standing water or wastes do not remain on the base longer than 1 hour after a spill or precipitation event unless the containers are elevated to protect them from contact with the liquid. A frequent practice is to elevate the containers on pallets to avoid contact with standing liquid. Another practice is to have the liquid drain into a collection sump equipped with a sump pump that is usually manually activated to remove the liquid. Depending on the type and concentration of contaminants, this liquid may be run through an oil-water separator, pumped to a collecting tank, or discharged to a treatment plant.

The integrity of the drums and containers must be maintaned in order to minimize the possibility of spills and leaks. There are several measures commonly taken to ensure this integrity. RCRA requires that container storage areas be inspected weekly for container leaks and deterioration (CFR 40, Part 264). This practice should be upheld, regardless of whether or not storage is temporary. Visual inspections for leaks and deterioration should be supplemented with air monitoring of volatile organics or combustibles. If drums begin to swell it will be necessary to vent them to relieve the pressure. Where overpressure is slight, hand tools may be used. Venting should be done remotely if containers are critically swollen (head raised several centimeters above chime).

A number of cover materials are available for minimizing corrosion of drums. Drums caps, which are available in chemical and UV light resistant rubber (Uniroyal Chemical, 1981), or as thin, clear polyethylene "shower caps" (BASCO, 1982), offer some degree of protection against weathering. Plastic sheets also have been used to cover drums during temporary storage. However, this practice is not safe because the sheeting can cause a "greenhouse effect" that can lead to overpressure in the drums. Canvas provides a more suitable cover material, however it makes inspections difficult. At the Stump Gap Creek site in West Point, Kentucky, empty drums and those containing sludges were stored in diked areas, covered with plastic, and topped with a foot of soil to minimize the "greenhouse effect" (U.S. EPA, 1981). The soil cover, however, makes it impossible to inspect the containers.

Roofing provides the highest degree of protection against weathering and may be advisable to minimize exposure of gas cylinders and explosives to sunlight and prevent contact of water reactive wastes with rainwater.

TRANSPORTATION

Regulations Affecting Transportation of Hazardous Wastes

The transportation of hazardous wastes is regulated by the Department of Transportation, the Environmental Protection Agency, the States, and, in some instances, by local ordinances and codes. In addition, more stringent Federal regulations also govern the transportation and disposal of highly toxic and hazardous materials such as PCBs and radioactive wastes. Applicable Department of Transportation regulations include:

- Department of Transportation 49 CFR 172-179
- Department of Transportation 49 CFR 387 (46 FR 30974, 47073)
- Department of Transportation DOT-E 8876.

The U.S. EPA regulations under RCRA (40 CFR Part 263) adopt DOT regulations pertaining to labeling, placarding, packaging, and spill reporting. RCRA regulations also impose certain additional requirements for compliance with the manifest system and recordkeeping. Specific shipment and packaging requirements are set forth under 49 CFR Part 173. Requirements for shipping containers are outlined in 40 CFR Part 178, and specifications for tank cars are given under 40 CFR Part 179. Additionally, Section 108 (b)(5) of CERCLA imposes upon motor carriers the financial responsibility requirements of Section 30 of the Motor Carrier Act of 1980 (PL 96-296). Section 30 requires the issuance of regulations for minimal levels of financial responsibility to cover public liability, property damage, and environmental restoration required as a result of waste transportation (U.S. EPA, 1981b).

State regulations required for hazardous material transportation are generally similar to the EPA transportation regulations. However, many of the States that have received EPA authorization to run their own hazardous waste programs under RCRA have adopted rules for transporters that are more stringent than the Federal program.

Local codes and ordinances may also govern the transportation of hazardous waste. These may include weight limitations on roads and bridges as well as prohibiting the use of some local roads.

Procedures for Offsite Transport

Vehicles for offsite transport of hazardous wastes must be DOT approved and must display the proper DOT placard. Liquid wastes must be hauled in tanker trucks that meet certain requirements and specifications for the waste type. Contaminated soils are hauled in box trailers and drums in box trailers or flat bed trucks. The trucks should be lined with plastic and/or covered with absorbent material. A typical 12-meter (40-foot) truck is capable of transporting about 80 drums in a single haul. The number of drums permitted, however, depends on the weight of the container material. The majority of States permit a gross weight of 36,000 kilograms (80,000 lb) in a single transporter. The number of drum stacks a hauler will permit depends on the distance of transport, the type of material, and the State regulations.

To comply with DOT and EPA regulations, drums must be handled as follows:

- Wastes must be contained in DOT-approved drums for the specific waste type
- Each drum must be individually labeled with the appropriate DOT hazard classification
- Drums must be thoroughly cleaned to remove any residue, defective parts must be replaced, and drums must show no visible evidence of pits, creases, or reduction in parent material thickness
- Drums containing incompatible wastes are not permitted to be hauled on the same vehicle.

Mildly contaminated soils, empty and crushed drums, and other debris not highly contaminated or DOT regulated are frequently hauled in dumpsters with sealed tailgates, particularly when the volume is so large that the cost is prohibitive to place the materials in drums. Where dumpsters are used, they should be lined with polyethylene sheeting and covered with polyethylene or a tarpaulin.

The hazardous waste manifest must be signed by the OSC and transporter before shipping bulk liquid or drums containing hazardous wastes. The manifest summarizes the total quantity of drums or liquid waste and their respective DOT chemical and hazard classification.

Before a vehicle is allowed to leave the site, it should be rinsed or scrubbed (Section 10). Before a bulk liquid container is permitted to leave the site it should be inspected for the following:

- Proper placarding
- Proper venting
- Closed valve positions
- Secured hatches
- Excess liquid levels
- Proper tractor-to-trailer hitch
- Cleanliness
- Tire conditions.

Before a box trailer is permitted to leave the site it should be inspected for the following items:

- Correct line installation
- Secured cover tarpaulin
- Locked lift gate
- Proper placarding
- Proper tractor-to-trailer hitch
- Excess waste levels
- Cleanliness (Di Napoli, 1982).

SECTION 11

ONSITE CONTAINMENT OPTIONS FOR BURIED DRUMS

The use of source control measures to contain or control migration of contaminants from buried drums generally is preferred over excavation and removal of wastes for the following reasons:

- Excavation of buried drums may present greater hazards to site workers and nearby residents.
- For sites with a large number of drums, excavation is likely to be more costly than onsite containment.

Excavation and removal of drums may be preferred. However, where onsite containment is not feasible, excavation is either more cost-effective (i.e., very few drums) or is necessary to protect public health or the environment. Generally, the design, application, and implementation of remedial measures for controlling or containing migration from buried drums are similar to those required for bulk wastes. However, two additional factors should be considered where large numbers of buried drums are involved:

- Added precautions may be required during remedial actions at drum sites to avoid explosion of drums close to the working surface.
- The nature and concentration of contaminants in the leachate may change with time as drums rupture and leak.

SELECTION OF REMEDIAL MEASURES FOR CONTROL OR CONTAINMENT OF WASTES

The NCP (Section 300.70) identifies a number of remedial measures for controlling or containing wastes from abandoned sites. These remedial measures can be grouped into six general categories. Within each category there are specific measures that can be applied to a given situation. The six categories are as follows:

- Surface capping and sealing (with or without gas venting)
- Surface water controls
- Groundwater pumping (with or without treatment)

- Subsurface drains (with or without treatment)
- Slurry walls
- In-situ treatment.

These categories are groupings of the available onsite containment options identified in the NCP. It is essential to consider site-specific conditions before selecting a specific remedial alternative. The selection should be conducted by a detailed process that is beyond the scope of this document.

The control and containment categories presented above are described in Tables 22 through 27 in terms of their applications, limitations, design and construction considerations, flexibility, reliability, and relative costs. It should be emphasized that these are categories of remedial alternatives and site-specific conditions will influence their selection or applicability. These remedial alternatives may be used singularly or in combination. However, the objectives of the remedial action must be clearly established prior to selection and remedial design. The objective can vary from simple procedures to minimize infiltration to a relatively complete hydrologic isolation of the site.

Tables 22 through 27 briefly show how these containment options apply to sites with buried drums. These tables are not intended to provide a site-specific detailed remedial alternative selective outline. Instead they provide a logical starting point for the remedial alternative selection process. In support of this selection process, there are a number of documents available on the detailed selection, design, and implementation of remedial techniques for waste sites. Some of the documents are listed below.

- *Handbook for Remedial Actions at Waste Disposal Sites.* (U.S. EPA, 1982b)

- *Leachate Plume Management.* (U.S. EPA, 1985, At Press)

- *Technical Handbook*: *Slurry Trench Construction for Pollution Migration Control*, (U.S. EPA, 1984b)

- *Alternatives to the Land Disposal of Hazardous Wastes*, (Toxic Waste Assessment Group, State of California, 1981).

- *Case Studies: Remedial Response at Hazardous Waste Sites*, (U.S. EPA, 1984c)

These and other pertinent documents should be consulted during preparation of the feasibility study and final design for remedial measures. Additional documents are in preparation and when available, should also be considered.

TABLE 22. CONSIDERATIONS FOR THE SELECTION, DESIGN, AND IMPLEMENTATION OF CAPPING AND SURFACE SEALING TECHNIQUES

Applications	Limitations	Design and Construction Considerations	Flexibility*	Reliability	Costs
• Minimize infiltration of precipitation • Control upward migration of gases • Control erosion with proper vegetative cover	• Liners may crack if landfill, etc., is subject to settling • Some sealants are incompatible with various wastes types	• Extensive subgrade preparation may be required to eliminate irregularities • Potential capping and sealing materials include: native fine-grained soils; bentonite; asphaltic materials; synthetic membranes, cements; and soil sealants. Waste-sealant incompatibility should be a major factor in selecting the most appropriate sealant or cap • Gas collection or venting systems may be required along with capping if gas migration is a problem • Precautions are needed to protect construction workers against explosion and fires during capping	• Design flexibility is limited when caps or sealants are used alone; however, when used together with slurry walls, dewatering, or gas migration controls, capping can greatly increase the flexibility of these techniques • Some liners have low tolerance to change in leachate composition and concentration	• High when compatibility and site-specific variables are considered in the selection of sealant or cap • Performance of some synthetic membranes and asphalt is affected by temperature extremes and sunlight • Prolonged contact with incompatible wastes can result in cracking, shrinkage, etc., of sealants and caps	• Capital costs are generally low • Operating and maintenance costs are relatively low • When used together with dewatering systems, sealants and caps can markedly decrease costs

*Flexibility is used to describe the ability of the remedial action to (1) withstand changes in leachate composition and quantity (operational flexibility) and (2) accomplish various remedial action objectives (design flexibility).

Note: Information in this table was gathered from JRB in-house sources, including staff experience, and is intended to provide general guidance.

TABLE 23. CONSIDERATIONS FOR THE SELECTION, DESIGN, AND IMPLEMENTATION OF SURFACE WATER CONTROLS

Applications	Limitations	Design and Construction Considerations	Flexibility*	Reliability	Costs
• Dikes and berms can be used to direct upland flow around a disposal area; provide erosion or flood protection; and contain contaminated runoff; • Ditches are used upslope of a disposal area to channel runoff to a downslope outlet • Chutes and downpipes are used to convey flow from top to bottom of a slope without causing erosion • Holding ponds and basins are used to temporarily store collected runoff	• Limited to small drainage areas • Earthen structures (dikes, berms, and and ditches) are generally intended as a temporary measure until more permanent actions can be taken	• Seeding and mulching, liners, or chemical stabilizers can be used to extend the life of these structures • Frequently, a combination of surface water controls are necessary	• Moderate to high--structures can be easily modified to account for changes in flow or volume	• Moderate --earthen structures are subject to erosion and flood damage • Continued maintenance is required for long-term use	• Low capital costs • Low O&M costs • Generally no salvage value.

*Flexibility is used to describe the ability of the remedial action to (1) withstand changes in leachate composition and quantity (operational flexibility) and (2) accomplish various remedial action objectives (design flexibility).

Note: Information in this table was gathered from JRB in-house sources, including staff experience, and is intended to provide general guidance.

TABLE 24. CONSIDERATIONS FOR THE SELECTION, DESIGN, AND IMPLEMENTATION OF GROUNDWATER PUMPING TECHNIQUES

Applications	Limitations	Design and Construction Considerations	Flexibility*	Reliability	Costs
• Use of extraction wells to remove or contain a plume or lower the water table beneath the disposal area • Use of injection wells to divert or dilute a plume and reinject clean groundwater • Use of injection and extraction wells in combination to contain a plume or recycle groundwater • Used together with capping and slurry walls to hydrologically isolate the site • Usable in rock and unconsolidated material • Usable in confined and unconfined aquifers	• Generally cost prohibitive in low transmissivity aquifers • Highly corrosive wastes can corrode pumps, casings, etc. • Viscous wastes may clog pumps	• Design and operation can be difficult in very heterogenous soils • Certain natural components of groundwater (i.e., iron, manganese, calcium carbonate) can clog well screens and reduce efficiency • Location of subsurface utilities and power lines must be determined • Wells can be tampered with; security measures are required • Steep hydraulic gradient can distort the cone of influence; more water tends to be pumped from upgradient areas	• High operational flexibility--can meet increased or decreased pumping depends • High design flexibility--can be used to accomplish almost any objective in controlling groundwater contamination	• Has electrical and mechanical parts that are subject to failure. However, parts can be replaced easily and quickly • Technology is well demonstrated, and experienced firms are widely available • If the systems operation is interrupted, contaminants can escape	• Capital costs are high to moderate • O&M costs are high • Generally requires treatment that greatly increases costs

*Flexibility is used to describe the ability of the remedial action to (1) withstand changes in leachate composition and quantity (operational flexibility) and (2) accomplish various remedial action objectives (design flexibility).

Note: Information in this table was gathered from JRB in-house sources, including staff experience, and is intended to provide general guidance.

TABLE 25. CONSIDERATIONS FOR THE SELECTION, DESIGN, AND IMPLEMENTATION OF SUBSURFACE DRAINAGE SYSTEMS

Applications	Limitations	Design and Construction Considerations	Flexibility*	Reliability	Costs
• Suitable for removing or containing a plume and for lowering the water table beneath a disposal area • May be better suited than pumping in low or highly variable transmissivity aquifers • Can be used with capping and slurry walls to hydrologically isolate a site	• Generally limited to shallow or floating plumes because of equipment limitations and the need for shoring during construction • Poorly suited to viscous contaminants • May be cost prohibitive in areas with frequent rock outcrops • May not be well suited above or below highly permeable soils; groundwater may flow preferentially into permeable layers	• Since drains are gravity flow systems, hydraulic gradient significantly affects design • High percentage of fines in soil may result in drain clogging • Subsurface features and utilities may interfere with installation and function • Large quantities of contaminated soils may be generated during excavation • Certain natural components of groundwater can form precipitates which clog drains and filters	• Moderate operational flexibility, can accomodate some changes in leachate volume but is considerably less flexible than pumping • Moderate design flexibility; can be used to accomplish several objectives in controlling groundwater contamination • Low tolerance to change in leachate viscosity or solubility	• System reliability is high if properly constructed and maintained • Technology is well proven although design and operation of systems for hazardous waste sites is limited • Sudden unexpected failures are unlikely since drains are a passive collection system • If drain failure does occur overtime, repairs are likely to be time consuming and costly; may need to employ pumping techniques to prevent escape of contamination during repairs	• Capital costs are high • O&M costs are low to moderate • Generally treatment is required that significantly increases O&M costs

*Flexibility is used to describe the ability of the remedial action to (1) withstand changes in leachate composition and quantity (operational flexibility) and (2) accomplish various remedial action objectives (design flexibility).

Note: Information in this table was gathered from JRB in-house sources, including staff experience, and is intended to provide general guidance.

TABLE 26. CONSIDERATIONS FOR THE SELECTION, DESIGN AND IMPLEMENTATION OF SLURRY WALLS

Applications	Limitations	Design and Construction Considerations	Flexibility*	Reliability	Costs
• Generally used together with capping, dewatering, etc. • Circumferential slurry walls used together with capping and pumping or drains to completely dewater a site • Used downgradient of a site to capture leachate • Used upgradient of pumping or drainage system to prevent dilution by clean water • Used together with dewatering upgradient of a site to divert the flow of groundwater around a site • Suitable for miscible, or non-miscible plumes	• Dewatering techniques (pumping or drains) are almost always required together with slurry walls to prevent over-topping of the wall or to minimize contact with leachate which could degrade the wall over time • Depth is limited only by the cost of excavation and capabilities of trenching equipment (24 meters modified backhoe; 45 meters or more for clamshell) • May be cost prohibitive in very rocky areas • Prolonged contact with some wastes may degrade the wall (i.e. strong acids and bases, inorganic salts, some organics)	• Wall must be keyed into an aquilude in order to to control water miscible or dense plumes. Bottom grouting can be used to seal fractured bedrock • Cement bentonite walls are less chemical resistant than soil bentonite walls • Cement bentonite walls are better suited than soil bentonite walls in areas subject to heavy traffic loads or other heavy stresses	• Design flexibility is low when used alone • When used together with other remedial actions, slurry walls can significantly increase flexibility • May have low tolerence to changes in leachate composition especially increased acidity or basicity or presence of highly concentrated slugs	• Technology is well demonstrated as a means of dewatering during construction but limited performance data is available on use of slurry walls at waste sites • Wall integrity may be degraded over time by prolonged contact with certain types of contaminants • Piping failure can result from improper mixing of backfill during construction • Permeability can be as low as 10^{-9} cm/sec for soil bentonite walls • Reliability can be increased by reinforcing the integrity of the wall with a synthetic liner	• Capital costs are very high • O&M costs are low • No salvage value • When used together with dewatering system, slurry walls can significantly decrease O&M costs

*Flexibility is used to describe the ability of the remedial action to (1) withstand changes in leachate composition and quantity (operational flexibility) and (2) accomplish various remedial action objectives (design flexibility).

Note: Information in this table was gathered from JRB in-house sources including staff experience, and is intended to provide general guidance.

TABLE 27. CONSIDERATIONS FOR THE SELECTION, DESIGN AND IMPLEMENTATION OF IN-SITU TREATMENT TECHNIQUES

Applications	Limitations	Design and Construction Considerations	Flexibility*	Reliability	Costs
• In-place treatment of a contaminated groundwater plume or contaminated soil to reduce contaminants to an acceptable level • Techniques include bioreclamation, oxidation-reduction, neutralization, precipitation, polymerization, etc.	• Bioreclamation: - suitable for relatively biodegradable wastes only (i.e., high BOD/COD ratio) - not well-suited where groundwater temperatures are less than 60°F - better suited to permeable substrate	• Bioreclamation: - requires hydraulic manipulation of the plume; plume can be contained by extraction wells or subsurface drains and can be recycled by injection wells - microorganisms can include indigenous organisms with or without nutrient additions, or adapted or genetically engineered organisms - Groundwater may require pH amendment if too acidic or basic - additional oxygen source is generally required (i.e., aeration, zone, hydrogen peroxide)	• Operational flexibility is limited; techniques are highly waste specific and have a low tolerance to change in leachate composition or concentration	• Methods have not been well demonstrated for treatment at hazardous waste sites • In the event of pump failure treatment chemicals, microorganisms and waste contaminants can escape containment	• Capital costs - moderate to high • O&M costs can be significantly lower than with pumping or drains since there is no need for offsite or aboveground treatment
	• Chemical treatment: - highly waste specific - generally limited to highly permeable substrata - chemicals used for treatment are often toxic and could further contaminate groundwater - may be difficult to achieve good contact between wastes and treatment reagents	• Chemical Treatment: - as with bioreclamation, requires hydraulic manipulation of the plume - Treatment reagents must be selected carefully since many of the reagents are toxic		• For certain chemical treatment methods (i.e., precipitation and polymerization) there is the potential for reversal of reactions	

*Flexibility is used to describe the ability of the remedial action to (1) withstand changes in leachate composition and quantity (operational flexibility) and (2) accomplish various remedial action objectives (design flexibility).

Note: Information in this table was gathered from JRB in-house sources, including staff experience, and is intended to provide general guidance.

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APPENDIX

HAZARDOUS WASTE COMPATIBILITY CHART

REACTIVITY GROUP NO.	REACTIVITY GROUP NAME													
1	Acids, Mineral, Non-oxidizing	1												
2	Acids, Mineral, Oxidizing		2											
3	Acids, Organic		G H	3										
4	Alcohols and Glycols	H	H F	H P	4									
5	Aldehydes	H P	H F	H P		5								
6	Amides	H	H GT				6							
7	Amines, Aliphatic and Aromatic	H	H GT	H		H		7						
8	Azo Compounds, Diazo Compounds, and Hydrazines	H G	H GT	H G	H G	H			8					
9	Carbamates	H G	H GT						G H	9				
10	Caustics	H	H	H		H				H G	10			
11	Cyanides	GT GF	GT GF	GT GF					G			11		
12	Dithiocarbamates	H GF F	H GF F	H GF GT		GF GT		U	H G				12	
13	Esters	H	H F						H G		H			13
14	Ethers	H	H F											
15	Fluorides, Inorganic	GT	GT	GT										
16	Hydrocarbons, Aromatic		H F											
17	Halogenated Organics	H GT	H F GT					H GT	H G		H GF	H		
18	Isocyanates	H G	H F GT	H G	H P			H P	H G		H P G	H G	U	
19	Ketones	H	H F						H G		H	H		
20	Mercaptans and Other Organic Sulfides	GT GF	H F GT						H G					
21	Metals, Alkali and Alkaline Earth, Elemental	GF H F	GF H F	GF H F	GF H F	GF H F	GF H	GF H	GF H	GF H	GF H	GF H	GF H GT	GF H
22	Metals, Other Elemental & Alloys as Powders, Vapors, or Sponges	GF H F	GF H F	GF					H F GT	U	GF H			
23	Metals, Other Elemental & Alloys as Sheets, Rods, Drops, Moldings, etc.	GF H F	GF H F						H F G					
24	Metals and Metal Compounds, Toxic	S	S	S			S	S			S			
25	Nitrides	GF H F	H F E	H GF	GF H E	GF H			U	H G	U	GF H	GF H	GF H
26	Nitriles	H GT GF	H F GT	H							U			
27	Nitro Compounds, Organic		H F GT			H					H E			
28	Hydrocarbons, Aliphatic, Unsaturated	H	H F			H								
29	Hydrocarbons, Aliphatic, Saturated		H F											
30	Peroxides and Hydroperoxides, Organic	H G	H E		H F	H G		H GT	H F E	H F GT		H E GT	H F GT	
31	Phenols and Cresols	H	H F						H G					
32	Organophosphates, Phosphothioates, Phosphodithioates	H GT	H GT						U		H E			
33	Sulfides, Inorganic	GT GF	H F GT	GT		H			E					
34	Epoxides	H P	H P	H P	H P	U		H P	H P		H P	H P	U	
101	Combustible and Flammable Materials, Miscellaneous	H G	H F GT											
102	Explosives	H E	H E	H E					H E		H E			H E
103	Polymerizable Compounds	P H	P H	P H					P H		P H	P H	U	
104	Oxidizing Agents, Strong	H GT		H GT	H F	H F	H F GT	H F GT	H E	H F GT		H E GT	H F GT	H F
105	Reducing Agents, Strong	H GF	H F GT	H GF	H GF F	GF H F	GF H	H GF	H G				H GT	H F
106	Water and Mixtures Containing Water	H	H						G					
107	Water Reactive Substances	← EXTREMELY REACTIVE!												
		1	2	3	4	5	6	7	8	9	10	11	12	13

Reproduced from best available copy.

HAZARDOUS WASTE COMPATIBILITY CHART (continued)

Reactivity Code	Consequences
H	Heat generation
F	Fire
G	Innocuous and non-flammable gas generation
GT	Toxic gas generation
GF	Flammable gas generation
E	Explosion
P	Violent polymerization
S	Solubilization of toxic substances
U	May be hazardous but unknown

Example:

H F GT — Heat generation, fire, and toxic gas generation

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	101	102	103	104	105	106	107
14	14																											
15		15																										
16			16																									
17				17																								
18					18																							
19						19																						
20				H	H	H	20																					
21				H E	GF H	GF H	GF H	21																				
22				H E	GF H		H GF F		22																			
23				H F						23																		
24											24																	
25				GF H	U	GF H	GF H	E				25																
26								H P			S	GF H	26															
27								H GF E				H GF E		27														
28									H E						28													
29																29												
30				H E	H	E	H F GT	H E	H G		H G	H GF F	H P GT		H P		30											
31					H P			GF H				GF H					H	31										
32								H									U		32									
33					H												H GT			33								
34							H P	H P	H P		H P	H P					H P	H P	U	H P	34							
101								H GF F				H GF F					H F GT					101						
102								H E	H E	H E	E	E					H E	H E		H E	H E	H E	102					
103								P H	P H	P H	P H	P H					P H	P H		P H			H E	103				
104	H F		H F	H GT	H F GT	H F	H F GT	H F E	H F E	H F		H F E	H F GT	H E	H F	H F	H G	H F	H F GT	H F GT	H F G	H F G	H E	H F GT	104			
105				H E	GF H	GF H	GF H						H GF	H E			H E	GF H	GT GF H		H	GF H	H E	H P GF	H F E	105		
106					H G			GF H	GF H		S	GF H								GT GF						GF GT	106	
107	DO NOT MIX WITH ANY CHEMICAL OR WASTE MATERIAL! EXTREMELY REACTIVE! →																											107

Source: Hatayama et al., 1980a